Broadband Trailing-Edge Noise

as a Canonical Benchmark Problem for Airframe Noise Predictions

Outcome of the BANC-III Workshop & Invitation for BANC-IV

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EXTENDED UPLOAD VERSION

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19th X-NOISE/CEAS Workshop: Broadband Noise of Rotors and Airframe
23–25 September 2015, La Rochelle, France

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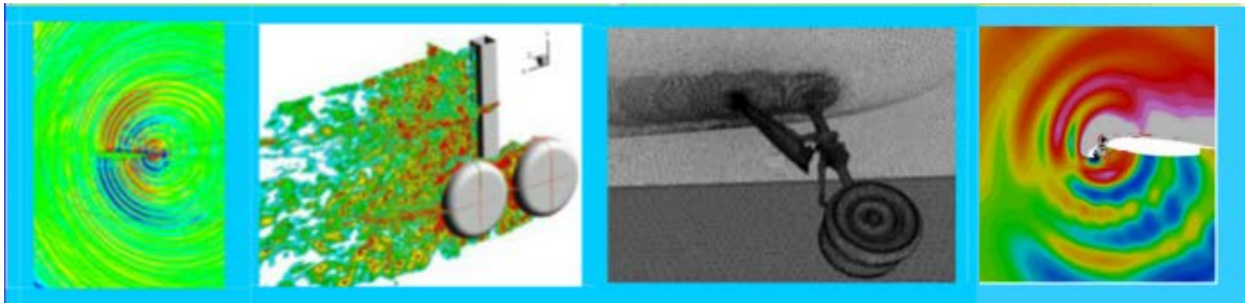
Workshops on Benchmark Problems for Airframe Noise Computations (BANC)

- Objectives of the BANC workshops (since 2010) are
  - to provide a forum for a thorough assessment of simulation-based noise-prediction tools;
  - to identify current gaps in physical understanding, experimental databases, and prediction capability for the major sources of airframe noise;
  - to help determine best practices, and accelerate the development of benchmark quality datasets;
  - to promote future coordinated studies.

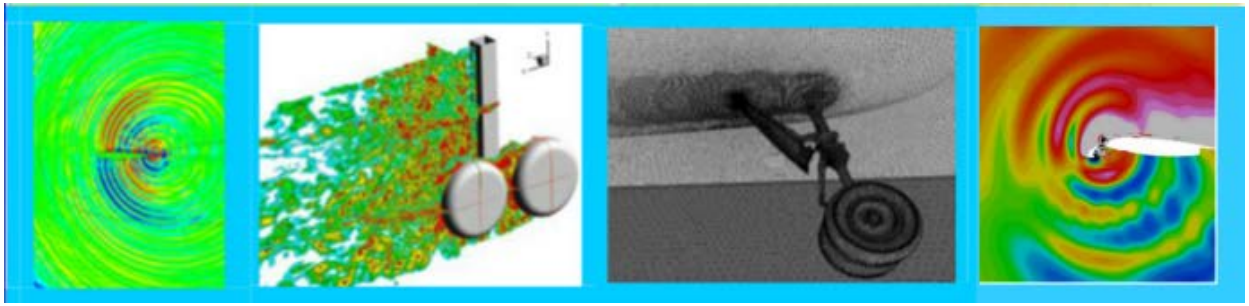
https://info.aiaa.org/tac/ASG/FDTC/ DG/BECAN_files_/



Workshops on Benchmark Problems for Airframe Noise Computations (BANC)

- Workshop categories:
  1. Airfoil trailing edge noise (TEN)
  2. Unsteady wake interference between a pair of inline tandem cylinders
  3. Minimal 4-wheel landing gear
  4. Partially-dressed, cavity-closed nose landing gear
  5. The LAGOON Simplified Landing Gear configuration tested by Airbus and ONERA
  6. Slat Noise (DLR/ONERA Configuration)
  7. Slat Noise (modified NASA 30P30N Configuration)
  8. Acoustic Propagation Phase of Airframe Noise Prediction

new since BANC-II



Workshops on Benchmark Problems for Airframe Noise Computations (BANC)

- Workshop categories:

	BANC-II-1	BANC-III-1
1. Airfoil trailing edge noise (TEN)	AIAA-2013-2123	AIAA-2015-2847
2. Unsteady wake interference between a pair of inline tandem cylinders		
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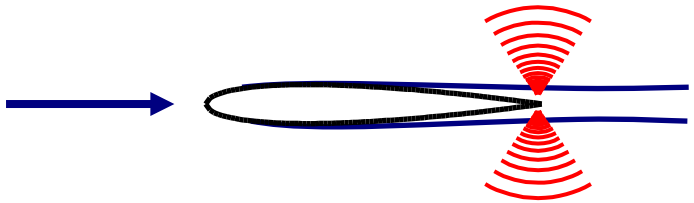


Test cases

- Provide $c_p(x_1)$, $c_f(x_1)$, near-wake mean flow / turbulence profiles, surface pressure spectra $G_{pp}(f)$, FF noise $L_p(f_c)$ for CASES#1-5 (***Re* = 1–1.5 Mio.**)

Case#1	**56 m/s 0°**	NACA0012
Case#2	**55 m/s 4°**	
Case#3	**53 m/s 6°**	
Case#4	**38 m/s 0°**	
Case#5	**60 m/s 4°**	DU-96-180

CASE#1: single core test case for those who could not afford the full matrix

For the full problem statement with more specified definitions of

- profile coordinates (sharp TE!)
- tripping devices (TBL-TE noise!)
- TBL transition locations
- ambient conditions, etc.
- data formatting instructions including templates

please contact michaela.herr@dlr.de.

Overview on contributions

- BANC-III-1 participants:

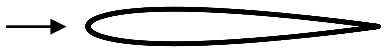
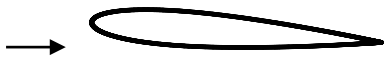
1) **PoliTo:** Andrea Iob, wavePRO, Torino, & Renzo Arina, Politecnico di Torino, Italy & Paul Batten / S. Chakravarthy, Metacomp Technologies, USA (CA)

2) **DLR:** Roland Ewert / Christof Rautmann, German Aerospace Center

3) **IAG:** Dimitrios Bekiropoulos / Mohammad Kamruzzaman, University of Stuttgart, Germany

4) **DTU:** Franck Bertagnolio, DTU Wind Energy, Technical University of Denmark

Overview on contributions

configuration/ participant			PoliTo	DLR	IAG	DTU
Case#1	56 m/s 0°		☑	☑	☑	☑
Case#2	55 m/s 4°		-	☑	☑	☑
Case#3	53 m/s 6°		-	☑	☑	☑
Case#4	38 m/s 0°		-	☑	☑	☑
Case#5	60 m/s 4°		-	☑	☑	☑

Overview of methods

Contribution PoliTo: IDDES with Large Eddy STimulation (CFD++ Code, Metacomp)

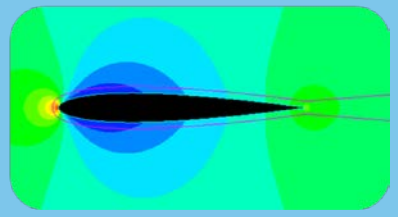
Hybrid RANS/LES coupled with Large-Eddy STimulation

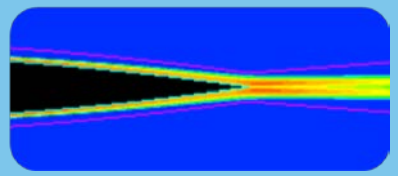
- LEST automatically converts RANS statistics into fluctuating turbulent velocity fields, suitable for sustaining an embedded LES

Mean Flow

RANS

- SA model
- QCR terms





Near Field

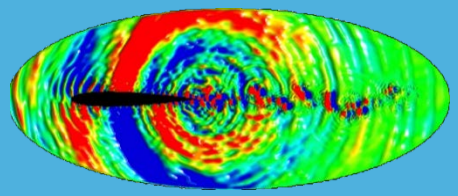
Synthetic turbulence

- Fourier-based method
- Implemented in CFD++

Stochastic velocity field

IDDES

- Implemented in CFD++



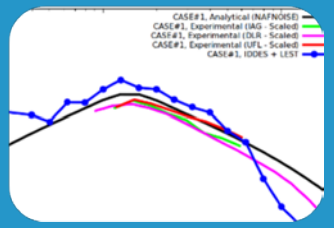
Far Field

FWH

- Time integration

Corrections

- 2D → 3D
- Span

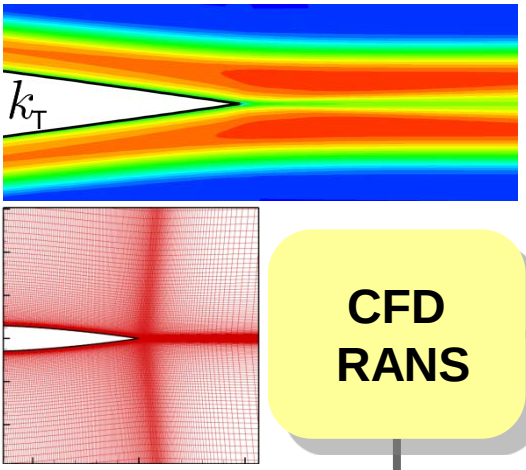


cf. AIAA-2014-2764; Iob et al.

Overview of methods

Contribution DLR: CAA-code PIANO with stochastic source model FRPM*

PIANO: Perturbation Investigation of Aeroacoustic Noise



mean flow; here:
DLR code TAU with SST

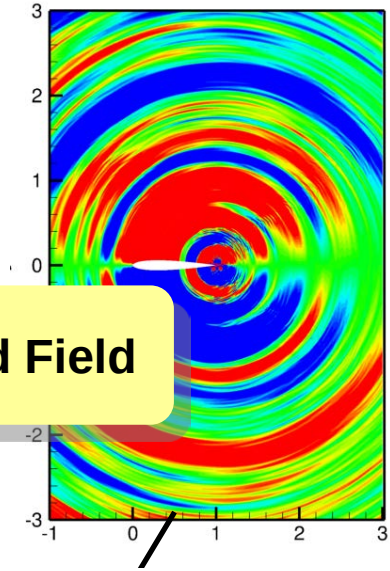
$\vec{u}_0, \rho_0, p_0$

CFD RANS

CAA APE

p'

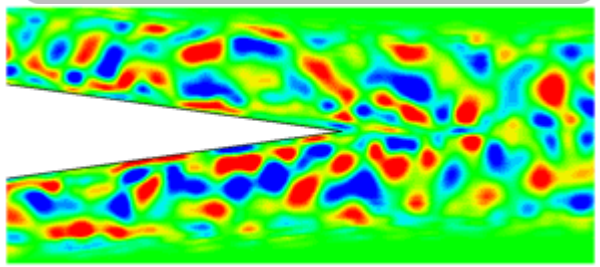
Sound Field



turbulence
k_T, ω

source
$\vec{L}'$

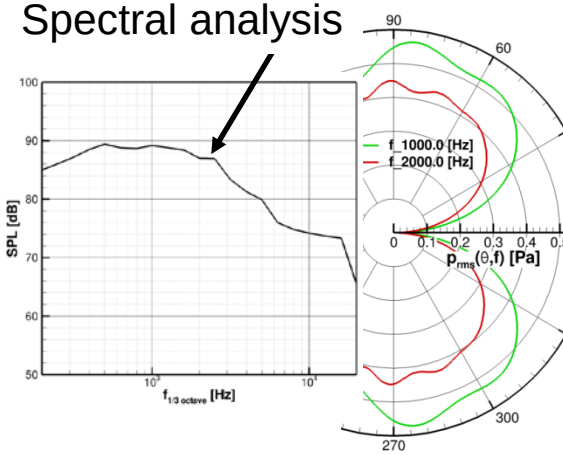
4D-Stochastic Sound Sources FRPM*



vortex sound sources

$$\vec{L}' = -\vec{\omega}_0 \times \vec{u}^t - \vec{\omega}^t \times \vec{u}_0$$

Spectral analysis

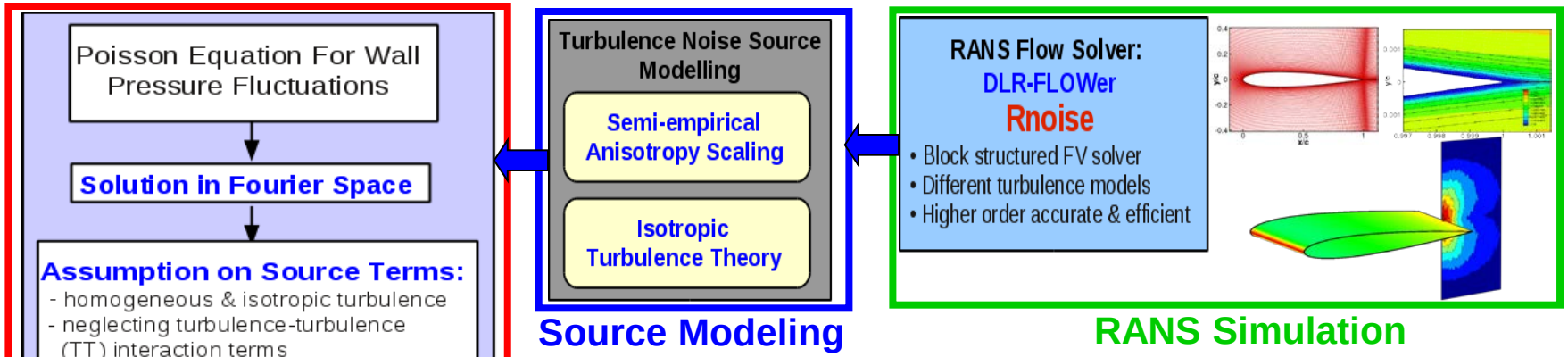


***Ewert, Comp. & Fluids (Vol. 37)**

cf. AIAA-2014-3298; Rautmann et al.

Rnoise: RANS based trailing-edge noise prediction model

- Simplified theoretical airfoil trailing-edge far-field noise prediction model based on steady RANS: highly accurate and very fast



$$P(k_1,k_3,\omega) = 4\rho_\infty^2 \left(\frac{k_1^2}{k_1^2+k_3^2}\right) \int_0^\infty \left[\frac{\mathrm{d}U_1(x_2)}{\mathrm{d}x_2}\right]^2 \Lambda_2(x_2)\,\tilde{\Phi}_{22}(k_1,k_3;x_2)\,\langle u_2^2(x_2)\rangle\,\Phi_m(\omega - k_1 U_c)\exp^{-2|k|x_2}\,\mathrm{d}x_2$$

(Parchen, 1998)

$$S(\omega) = \frac{b}{4\,\pi\,r^2}\int_{-\infty}^{\infty}\frac{\omega}{c_\infty k_1}P(k_1,0,\omega)\,\mathrm{d}k_1$$

(Brooks & Hodgson, 1981)

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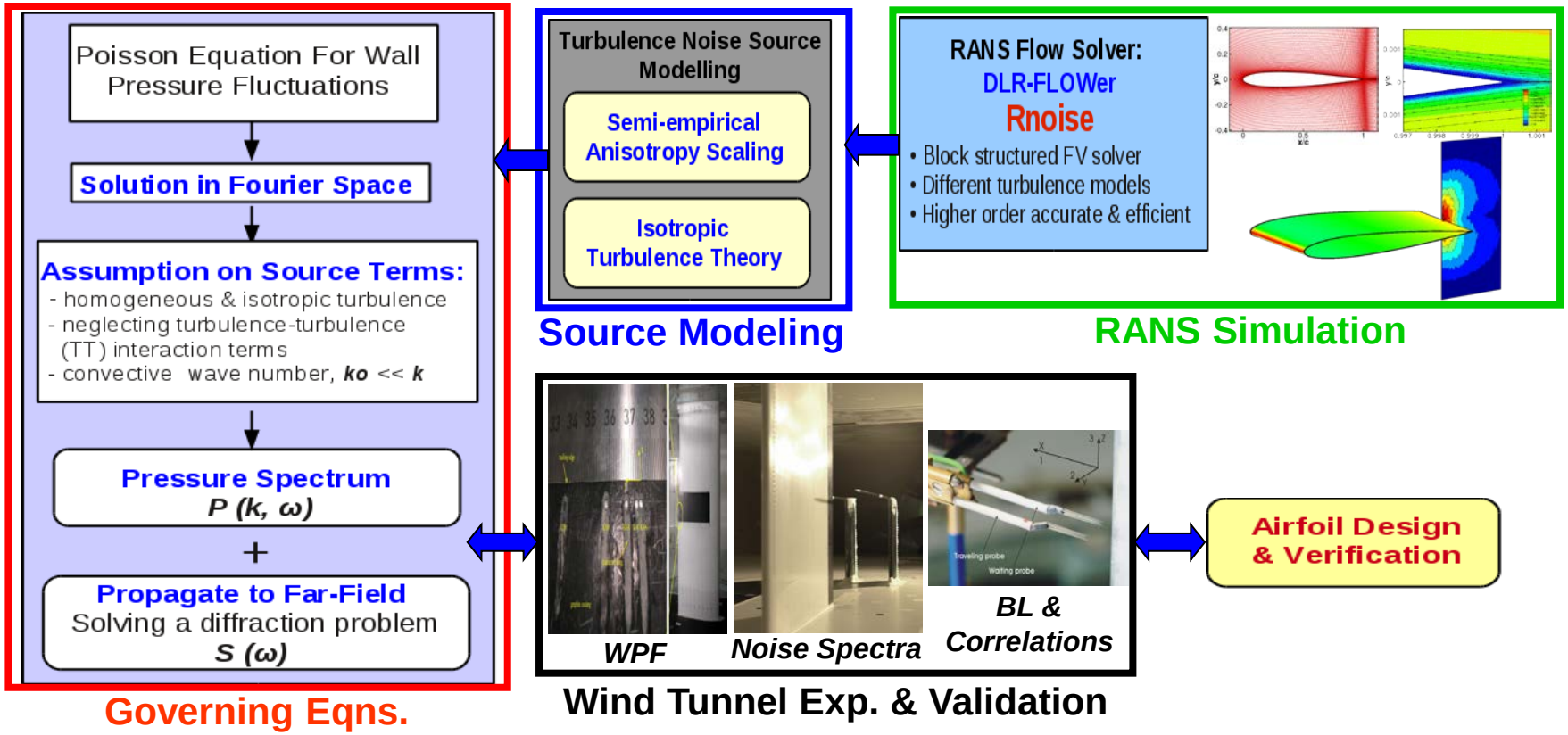
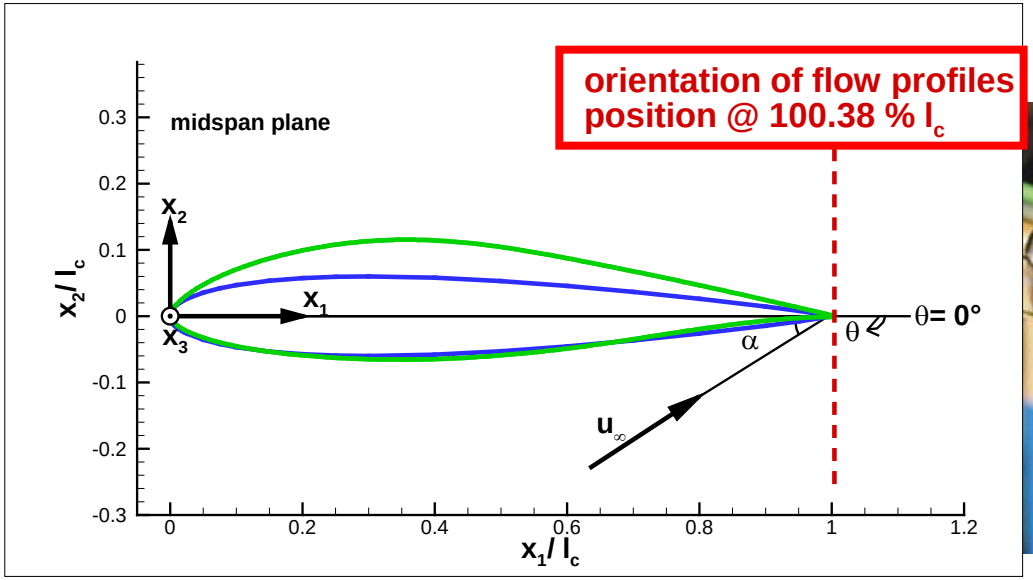
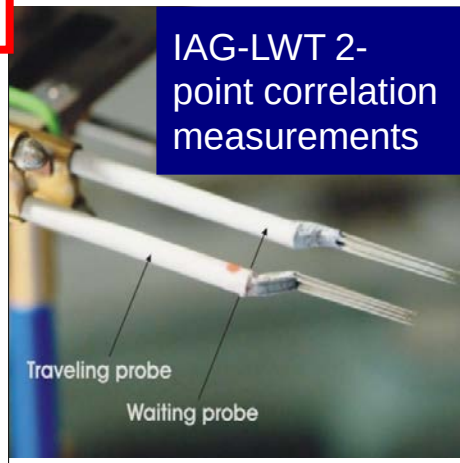


TEN modeling @ DTU Wind Energy

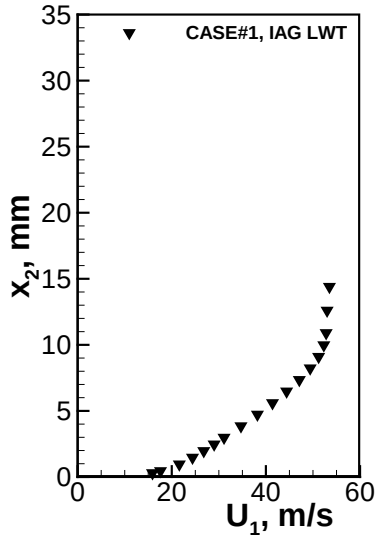
- **Airfoil flow calculation – EllipSys2D**
  - ✓ Classical 2D incompressible RANS solver
  - ✓ $k-\omega$ SST turbulence model
- **Surface pressure calculation – Blake-TNO**
  - ✓ Using anisotropic turb. stress tensor by stretching each direction of space using stretching factors
  - ✓ Stretching factors tuned using mean pressure gradient (Bertagnolio et al., 2014)
- **Farfield noise – diffraction theory (Brooks & Hodgson, 1981)**
- **Important note concerning calculations:**
  - ✓ Trip-tapes are modeled by fixing transition and using higher intermittency factor in $Re-\theta$ transition model

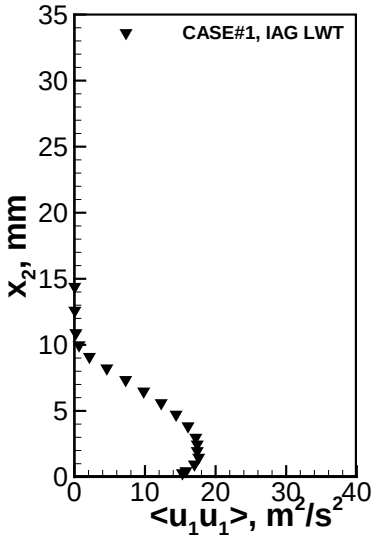
Near-wake flow characteristics

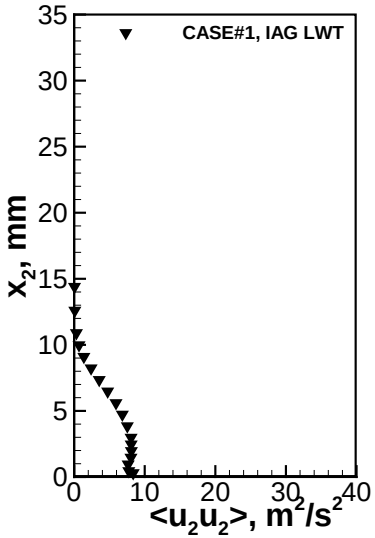


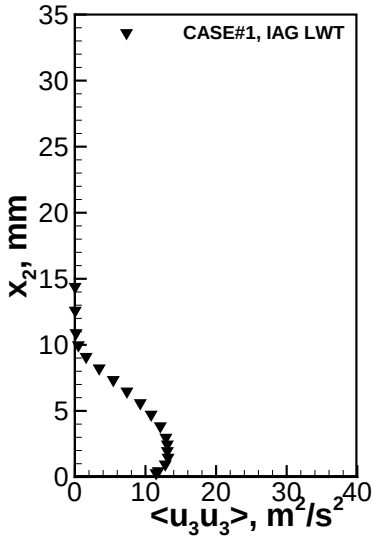


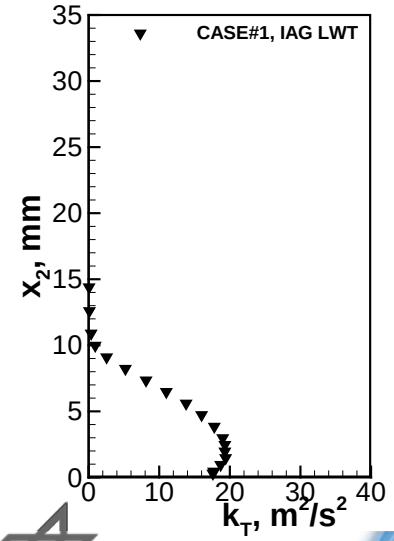
Near-wake flow characteristics CASE#1 SS

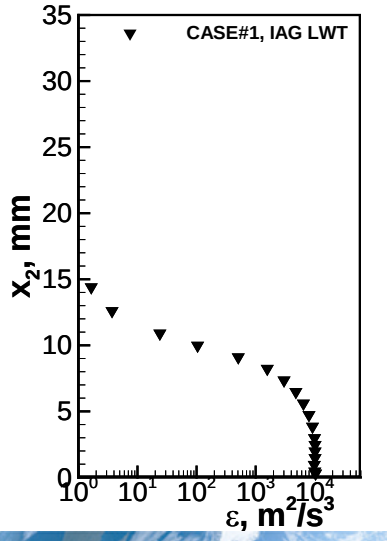


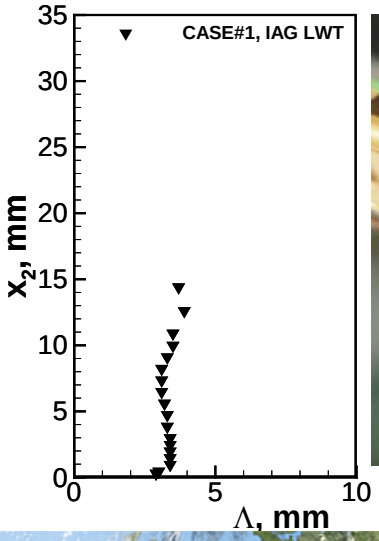


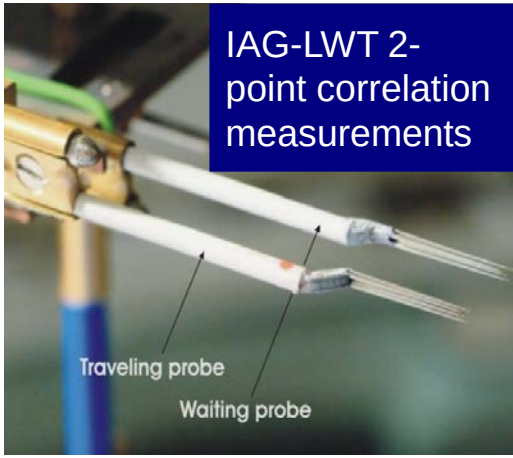










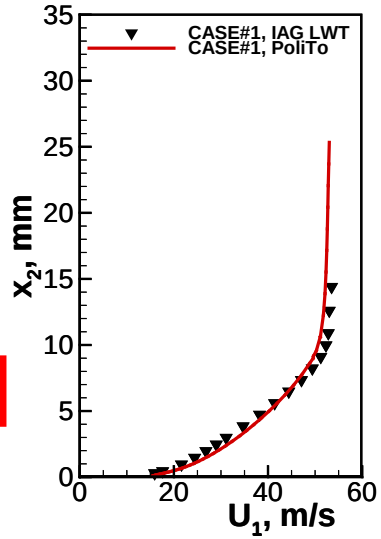


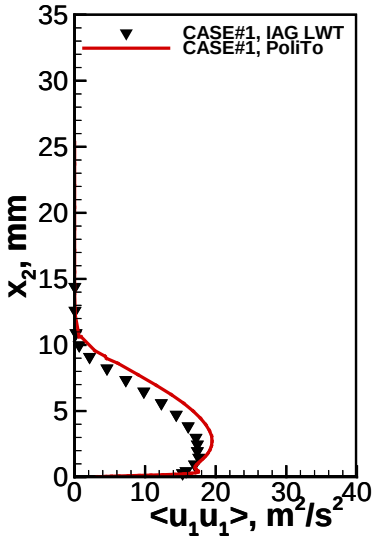
Overall comparisons

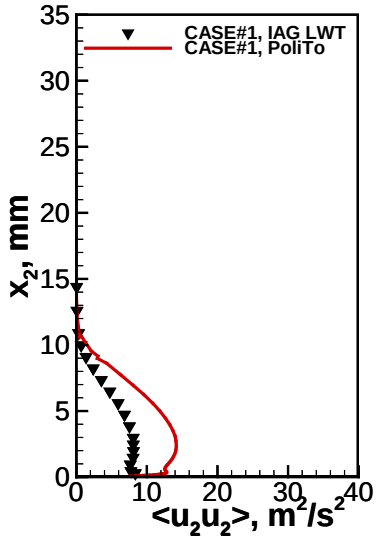
Aerodynamical data

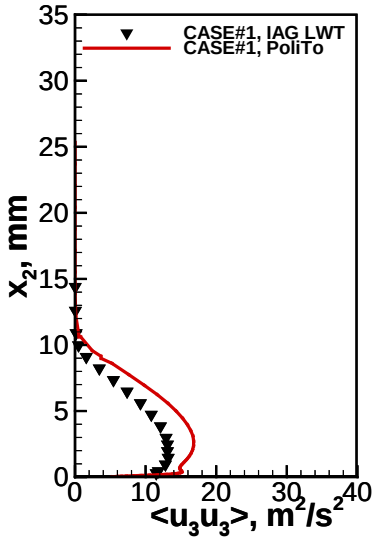
Near-wake flow characteristics CASE#1 SS

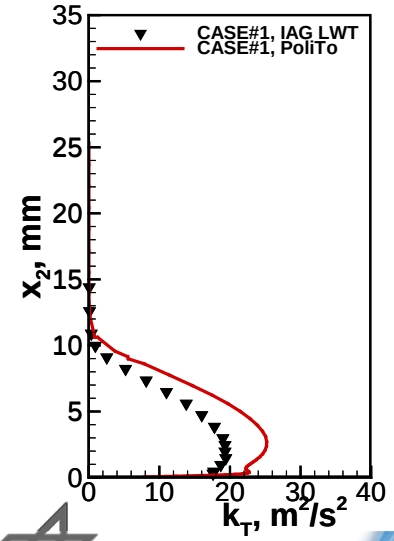
PoliTo

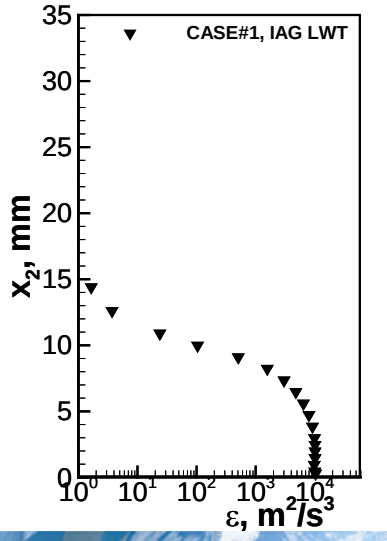


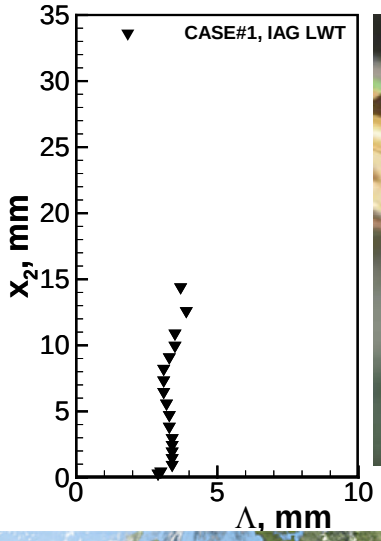


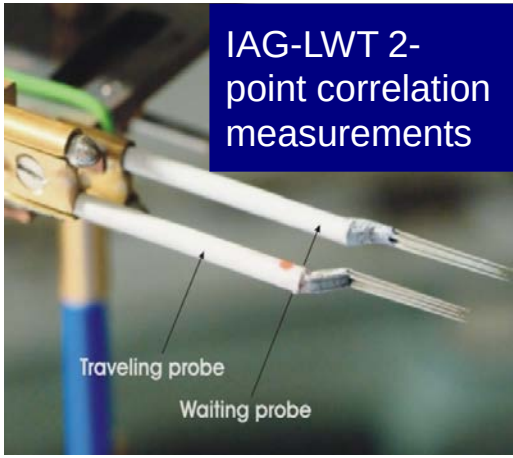












Overall comparisons

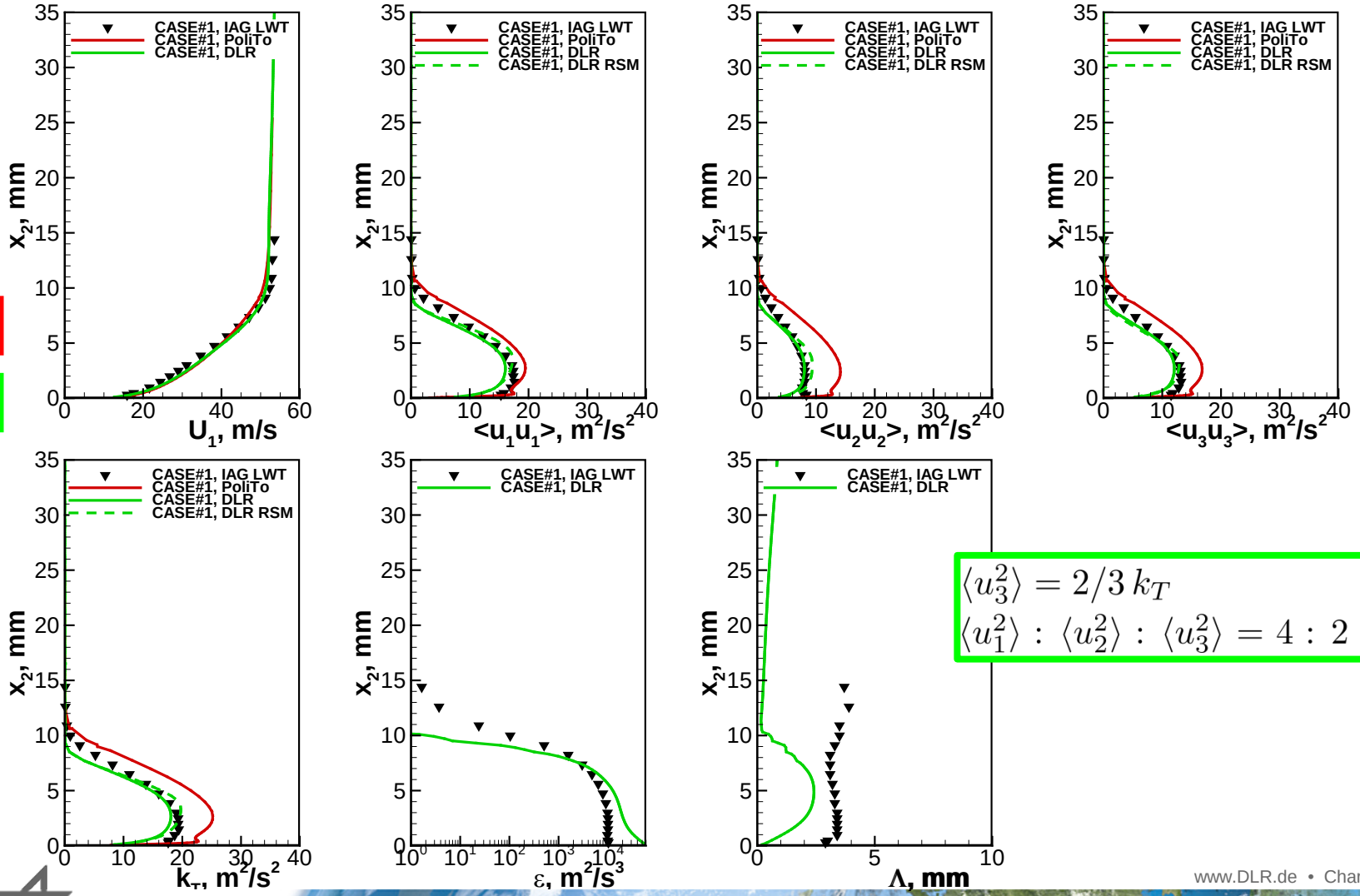
PoliTo: CFD^{++} + SA (+ QCR terms)
DLR: TAU + SST (4 : 2 : 1)

Aerodynamical data

Near-wake flow characteristics CASE#1 SS

PoliTo

DLR



$$\langle u_3^2 \rangle = 2/3\, k_T$$
$$\langle u_1^2 \rangle : \langle u_2^2 \rangle : \langle u_3^2 \rangle = 4 : 2 : 3$$

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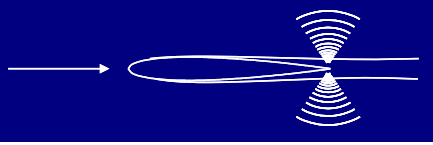

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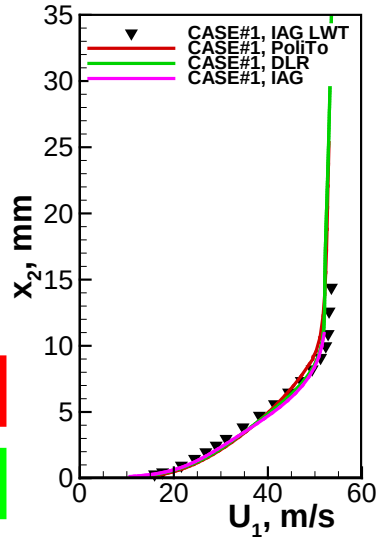

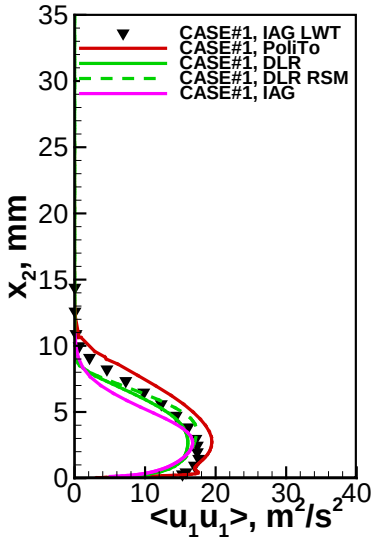

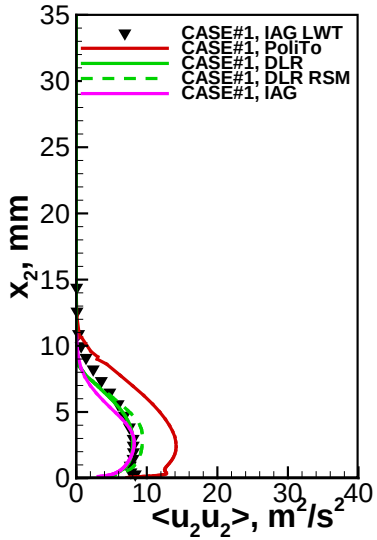

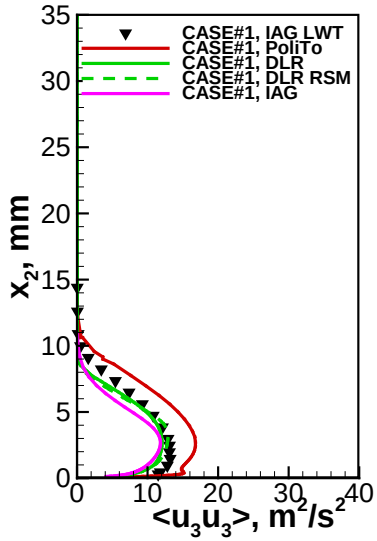

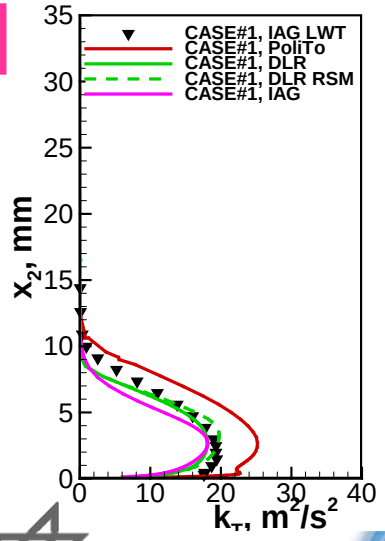

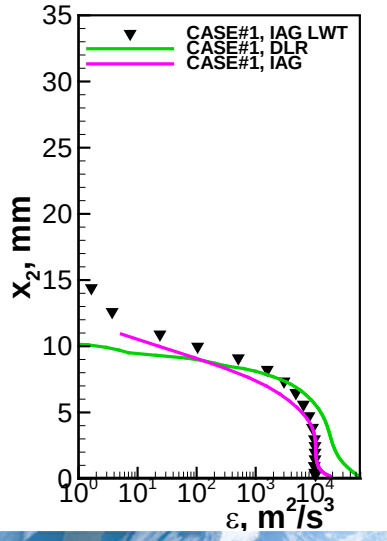

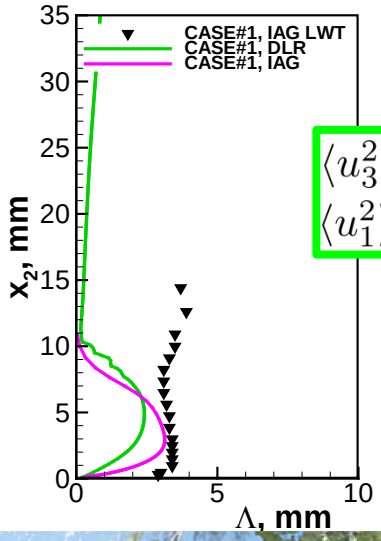

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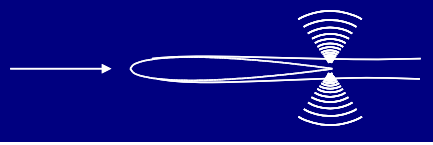
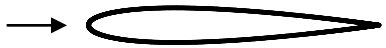


Near-wake flow characteristics CASE#1 SS

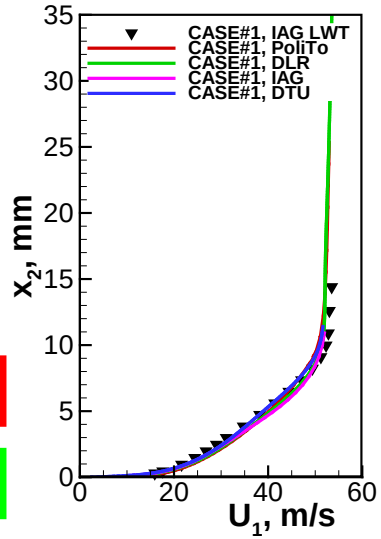


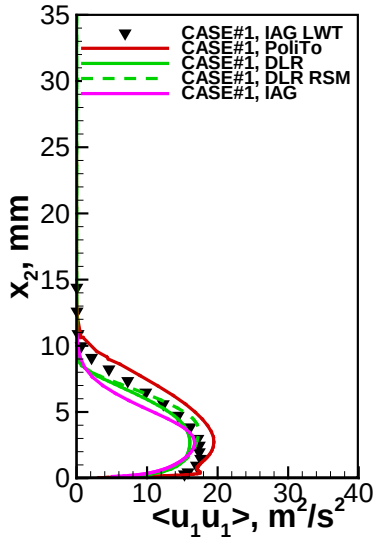
PoliTo

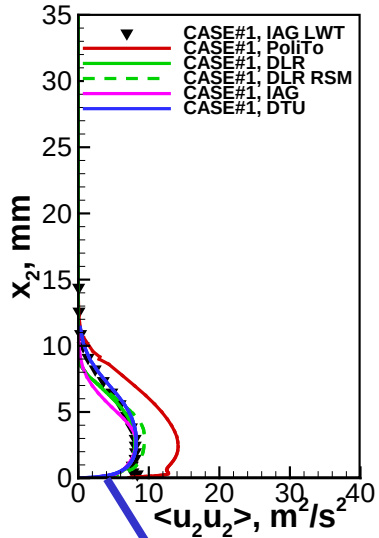
DLR

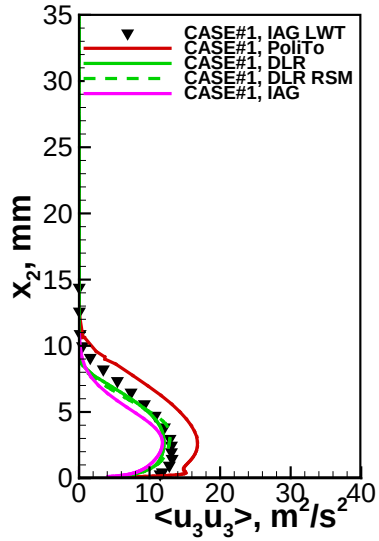
IAG

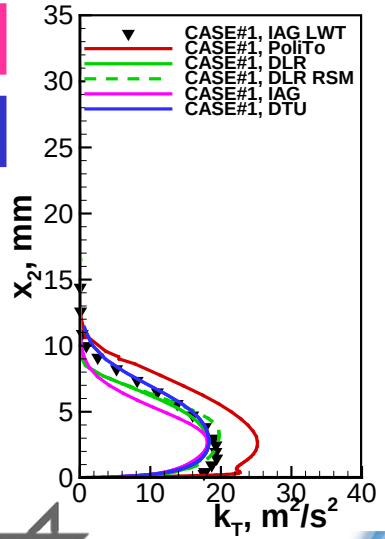
DTU

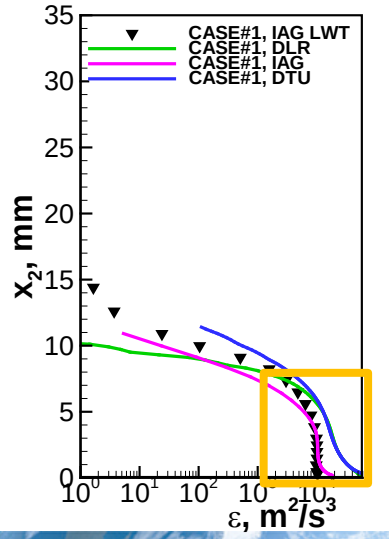


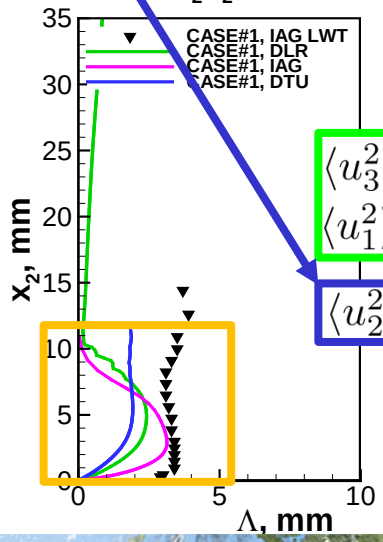












$\langle u_3^2 \rangle = 2/3\, k_T$

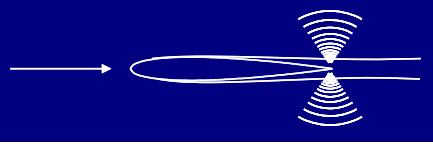
$\langle u_1^2 \rangle : \langle u_2^2 \rangle : \langle u_3^2 \rangle = 4 : 2 : 3$

$\langle u_2^2 \rangle = 0.45\, k_T$

Overall comparisons

Aerodynamical data

PoliTo: CFD^{++} + SA (+ QCR terms)
DLR: TAU + SST (4 : 2 : 1)
IAG: FLOWer + SST (+ anisotropy model)
DTU: EllipSys2D + SST

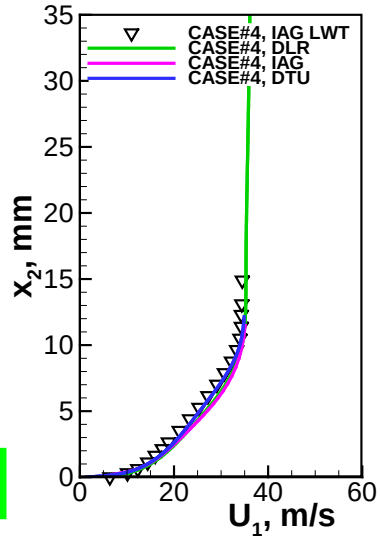


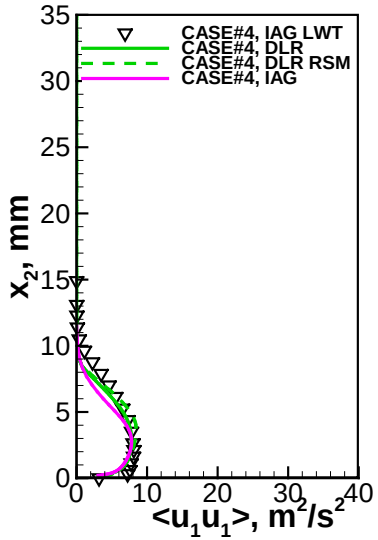
Near-wake flow characteristics CASE#4 SS

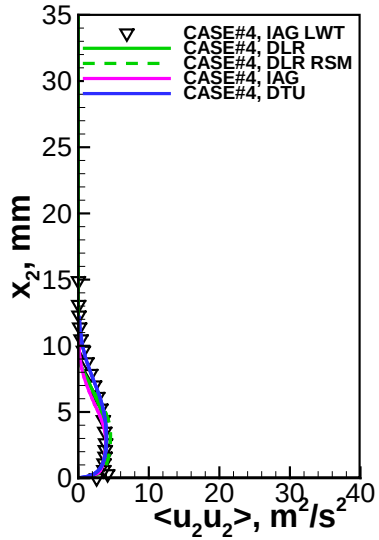
DLR

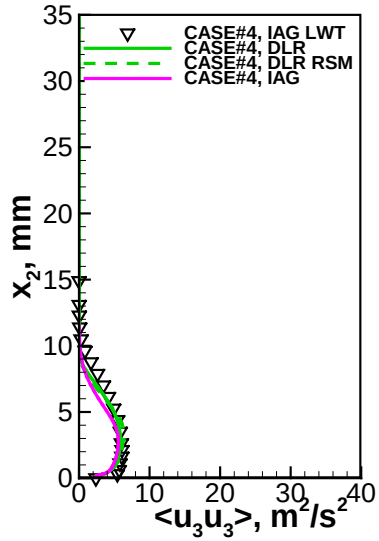
IAG

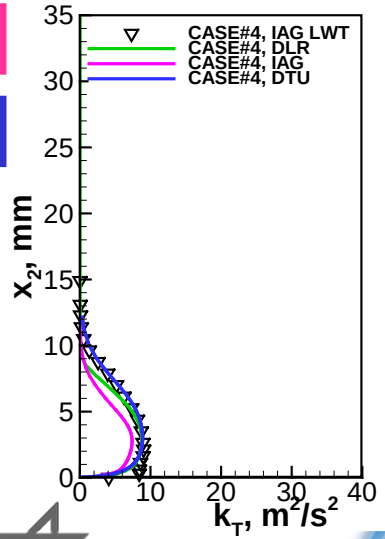
DTU

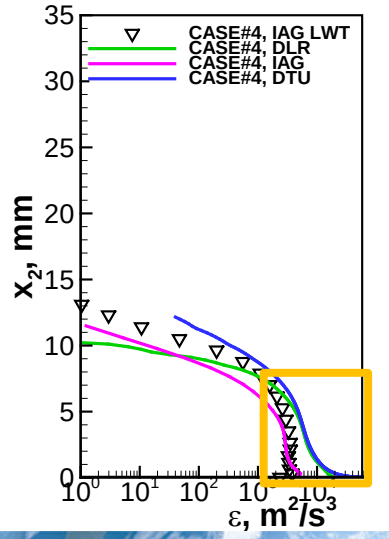


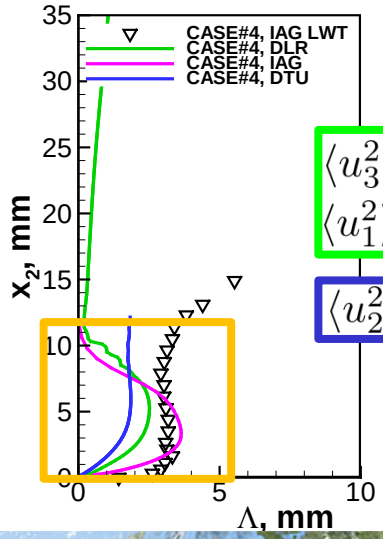












$$\langle u_3^2 \rangle = 2/3\, k_T$$

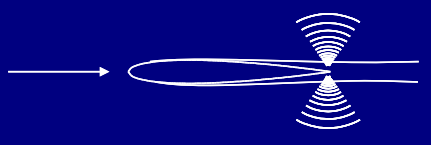
$$\langle u_1^2 \rangle : \langle u_2^2 \rangle : \langle u_3^2 \rangle = 4 : 2 : 3$$

$$\langle u_2^2 \rangle = 0.45\, k_T$$

Overall comparisons

Aerodynamical data

PoliTo: CFD^{++} + SA (+ QCR terms)
DLR: TAU + SST (4 : 2 : 1)
IAG: FLOWer + SST (+ anisotropy model)
DTU: EllipSys2D + SST

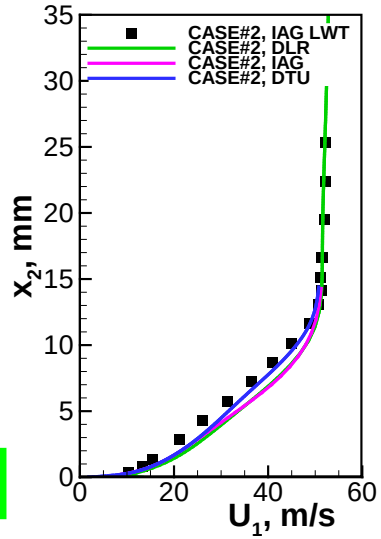


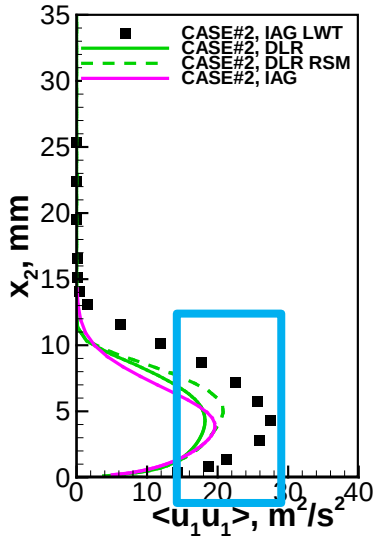
Near-wake flow characteristics CASE#2 SS

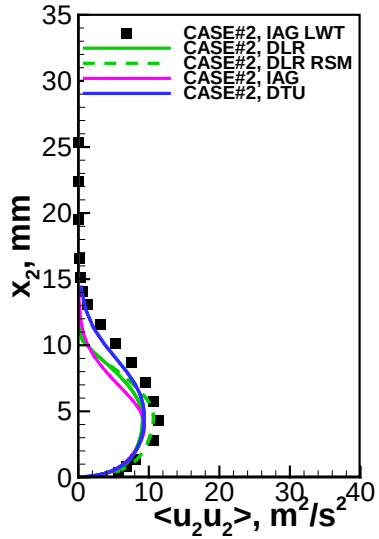
DLR

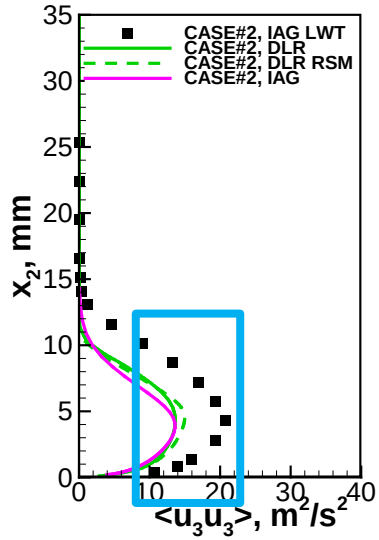
IAG

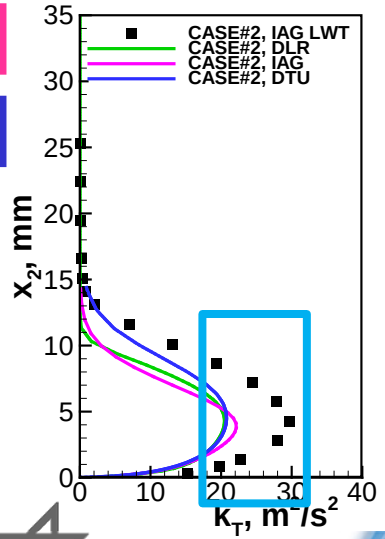
DTU

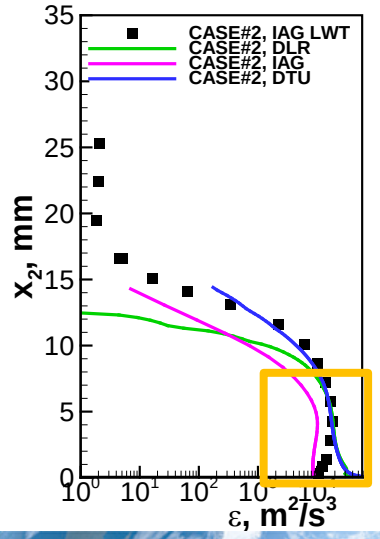


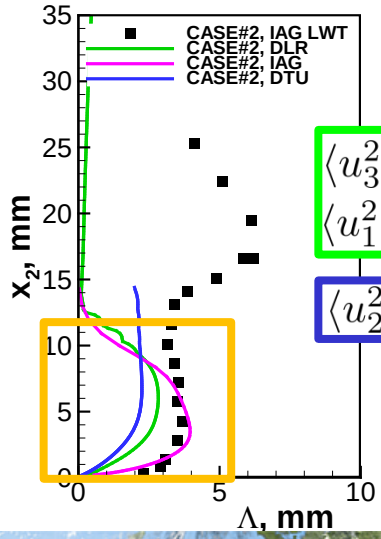












$$\langle u_3^2 \rangle = 2/3\, k_T$$

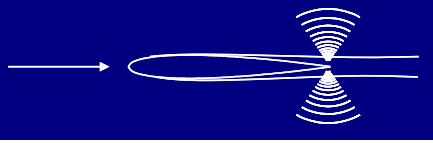
$$\langle u_1^2 \rangle : \langle u_2^2 \rangle : \langle u_3^2 \rangle = 4 : 2 : 3$$

$$\langle u_2^2 \rangle = 0.45\, k_T$$

Overall comparisons

Aerodynamical data

PoliTo: CFD^{++} + SA (+ QCR terms)
DLR: TAU + SST (4 : 2 : 1)
IAG: FLOWer + SST (+ anisotropy model)
DTU: EllipSys2D + SST

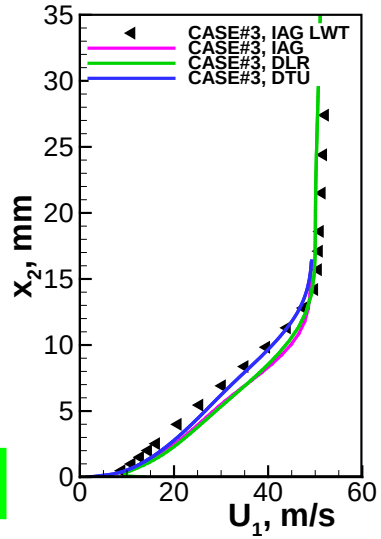


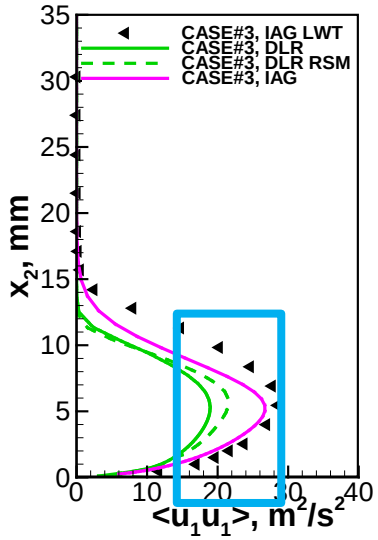
Near-wake flow characteristics CASE#3 SS

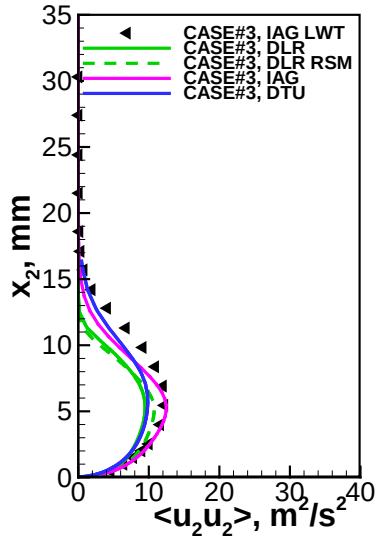
DLR

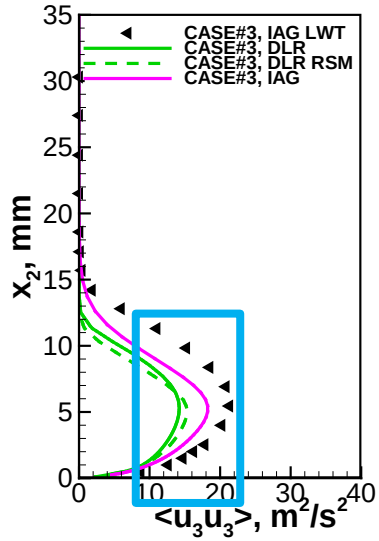
IAG

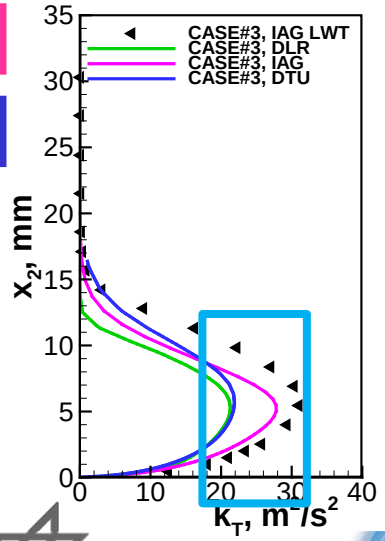
DTU

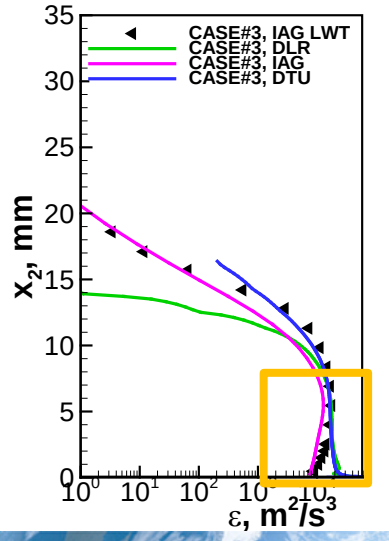


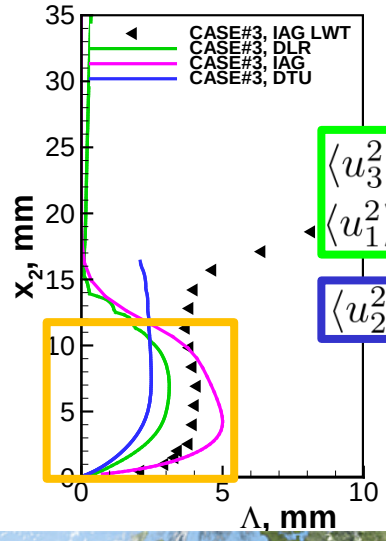












$$\langle u_3^2 \rangle = 2/3\, k_T$$

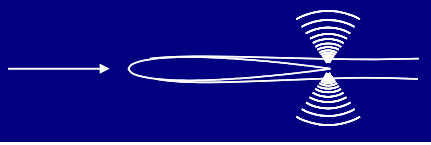
$$\langle u_1^2 \rangle : \langle u_2^2 \rangle : \langle u_3^2 \rangle = 4 : 2 : 3$$

$$\langle u_2^2 \rangle = 0.45\, k_T$$

Overall comparisons

Aerodynamical data

PoliTo: CFD^{++} + SA (+ QCR terms)
DLR: TAU + SST (4 : 2 : 1)
IAG: FLOWer + SST (+ anisotropy model)
DTU: EllipSys2D + SST

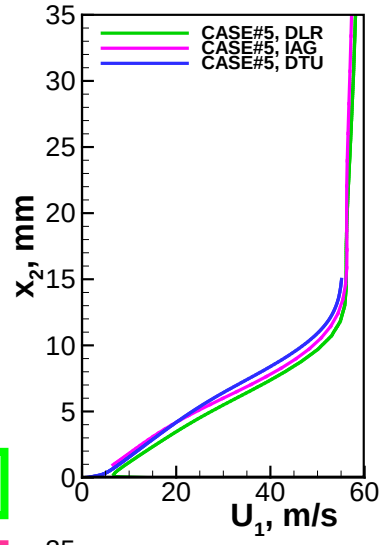


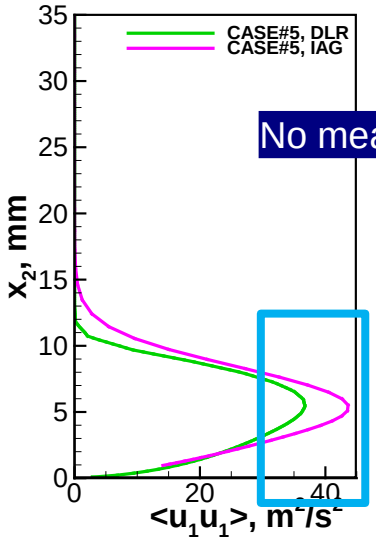
Near-wake flow characteristics CASE#5 SS

DLR

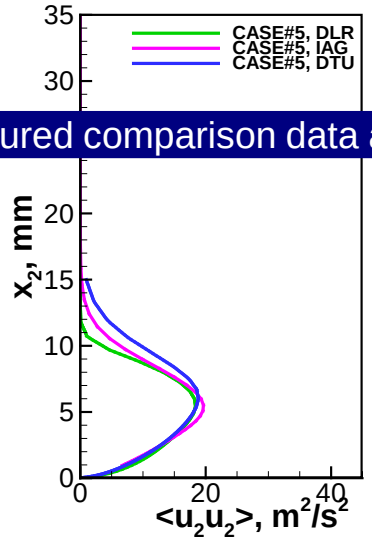
IAG

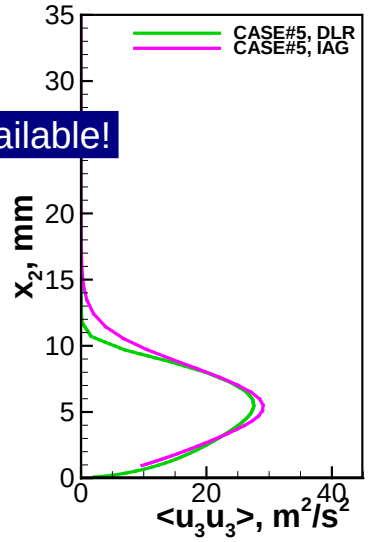
DTU

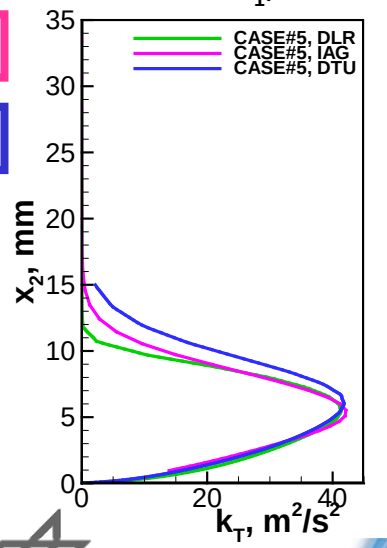


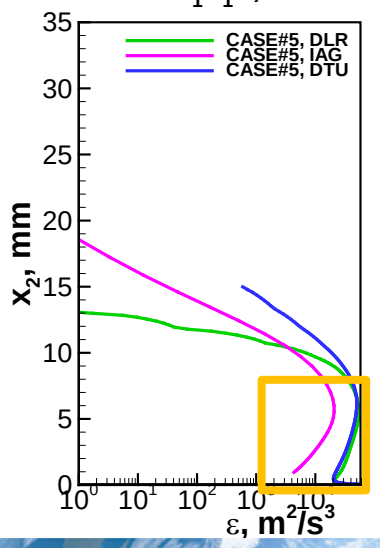


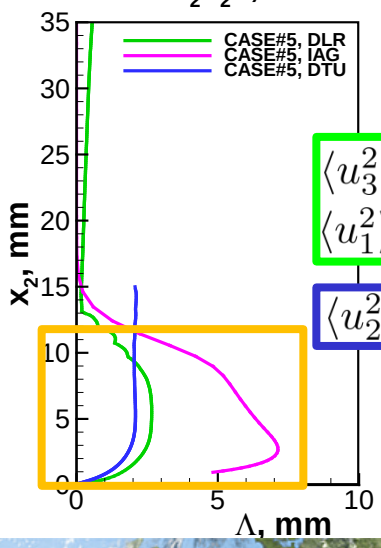
No measured comparison data available!









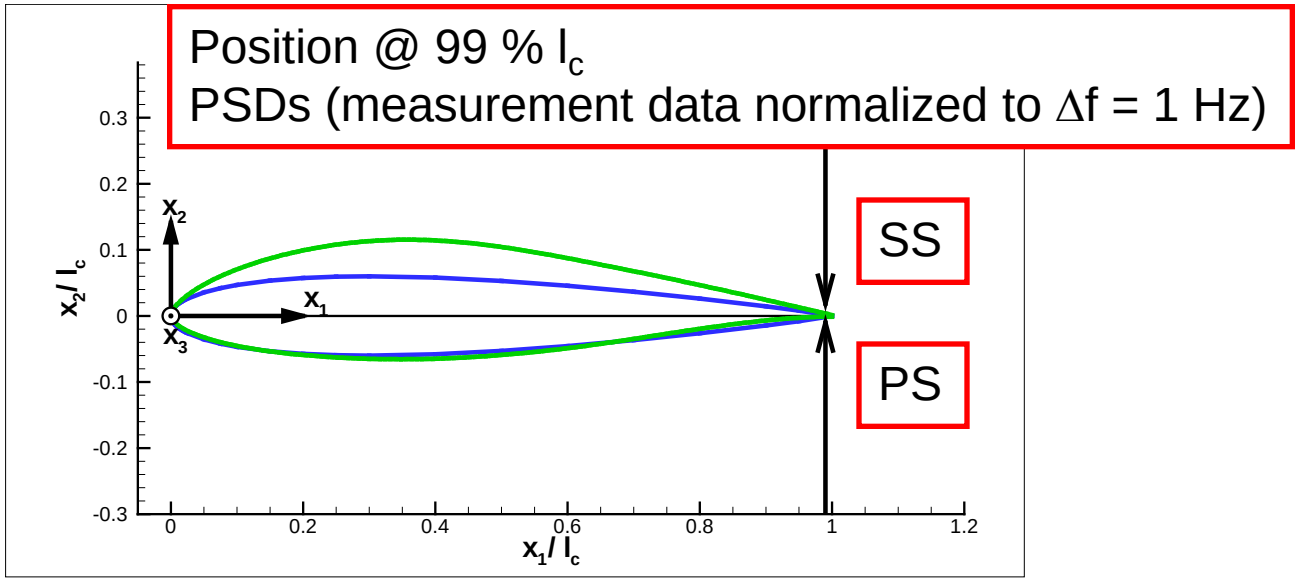


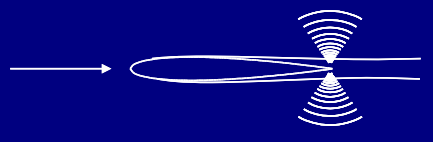
$$\langle u_3^2 \rangle = 2/3\, k_T$$
$$\langle u_1^2 \rangle : \langle u_2^2 \rangle : \langle u_3^2 \rangle = 4 : 2 : 3$$

$$\langle u_2^2 \rangle = 0.45\, k_T$$

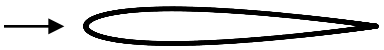
Overall comparisons

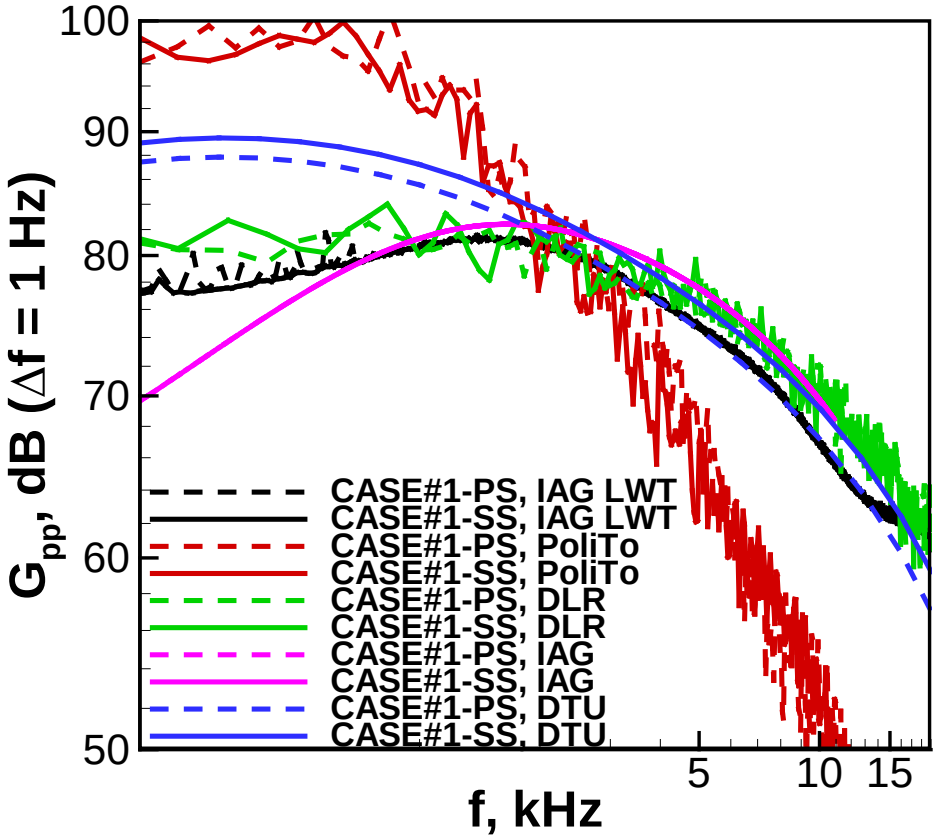
Surface pressure data

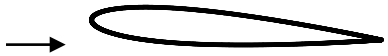


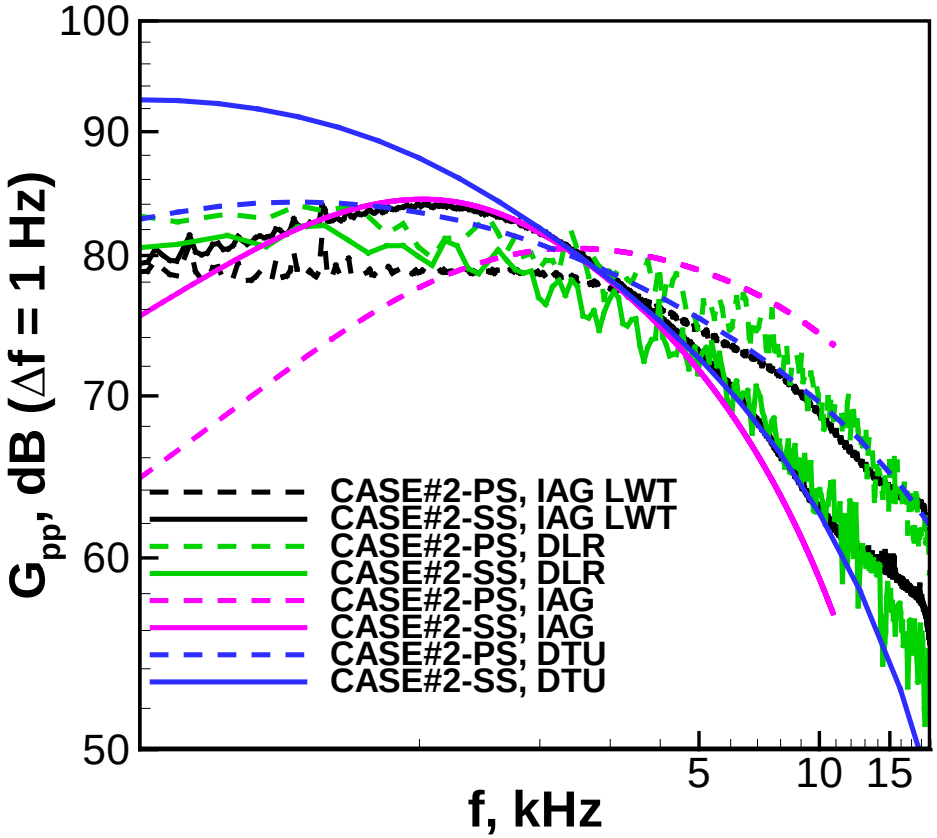


Unsteady surface pressure PSD $G_{pp}(f)$ CASES#1 & #2







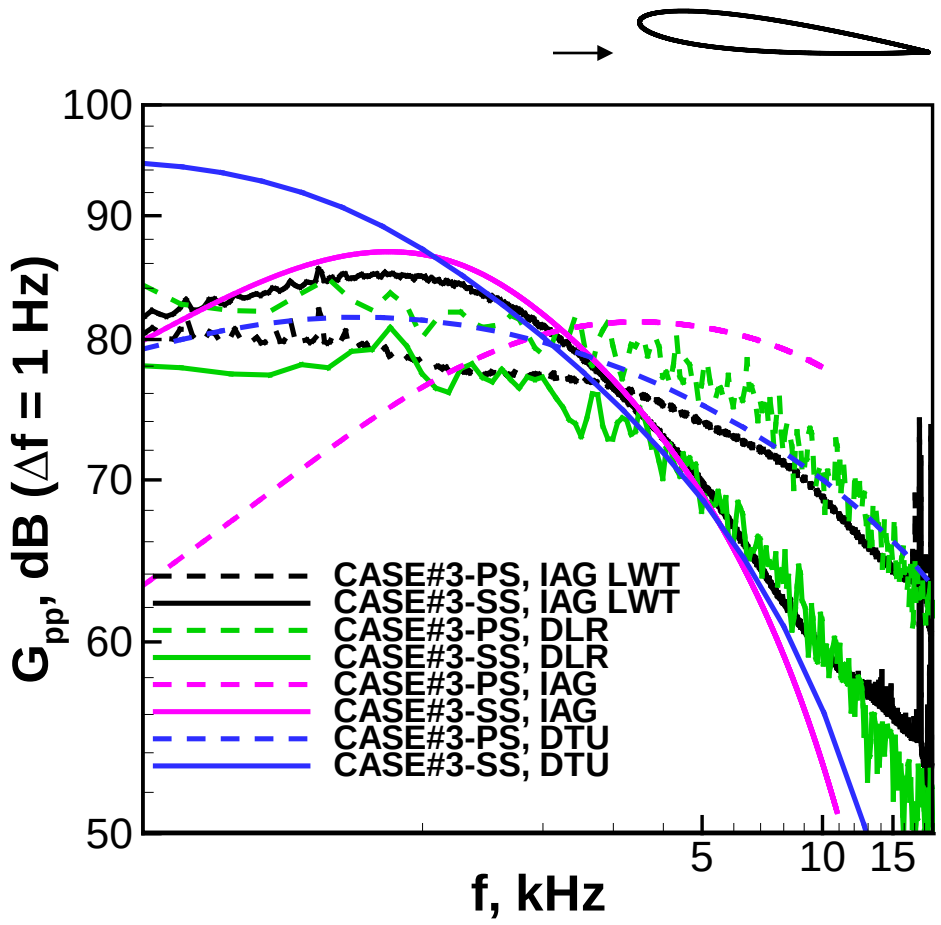


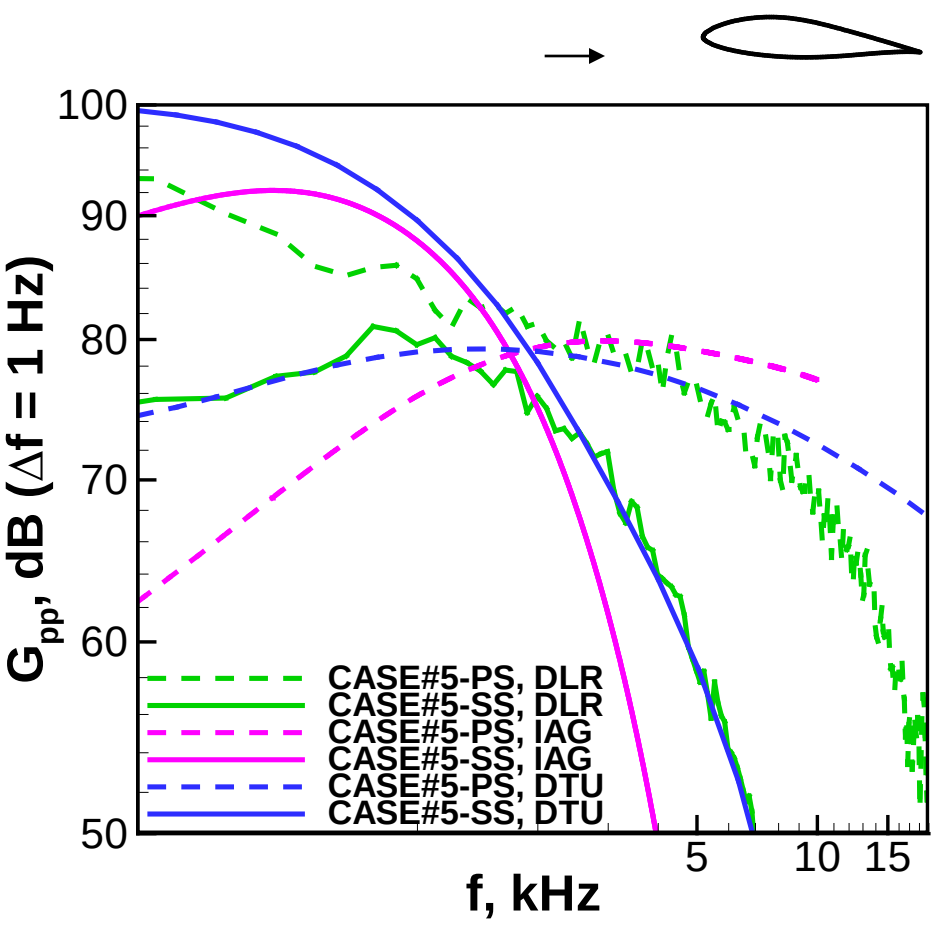
Overall comparisons

Surface pressure data

PoliTo: IDDES-LEST
DLR: PIANO-FRPM
IAG: Rnoise 'Blake-TNO' derivative
DTU: 'Blake-TNO' derivative

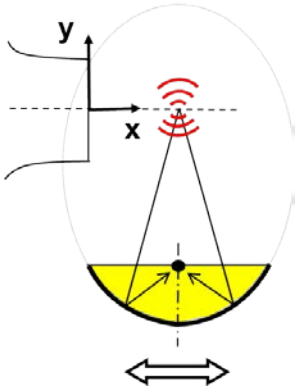
Unsteady surface pressure PSD $G_{pp}(f)$ CASES#3 & #5



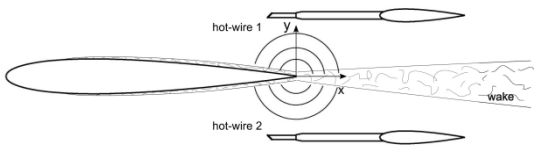


no measured comparison data available!

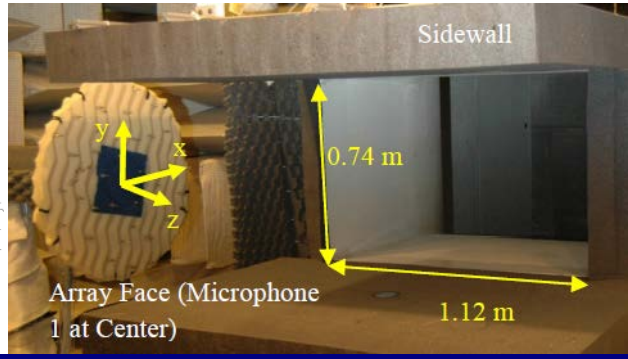
Overall comparisons



CPV @ IAG LWT

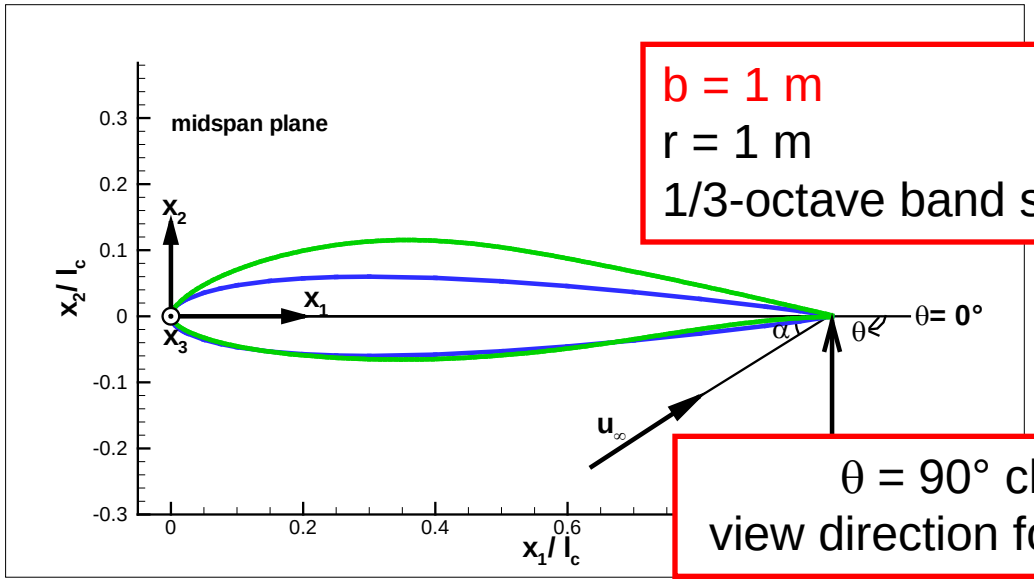


array @ UFAFF



TEN farfield noise data

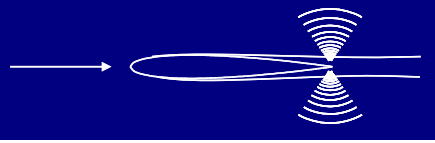
elliptic mirror @ DLR AWB



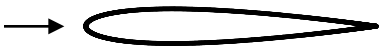
b = 1 m
r = 1 m
1/3-octave band spectra

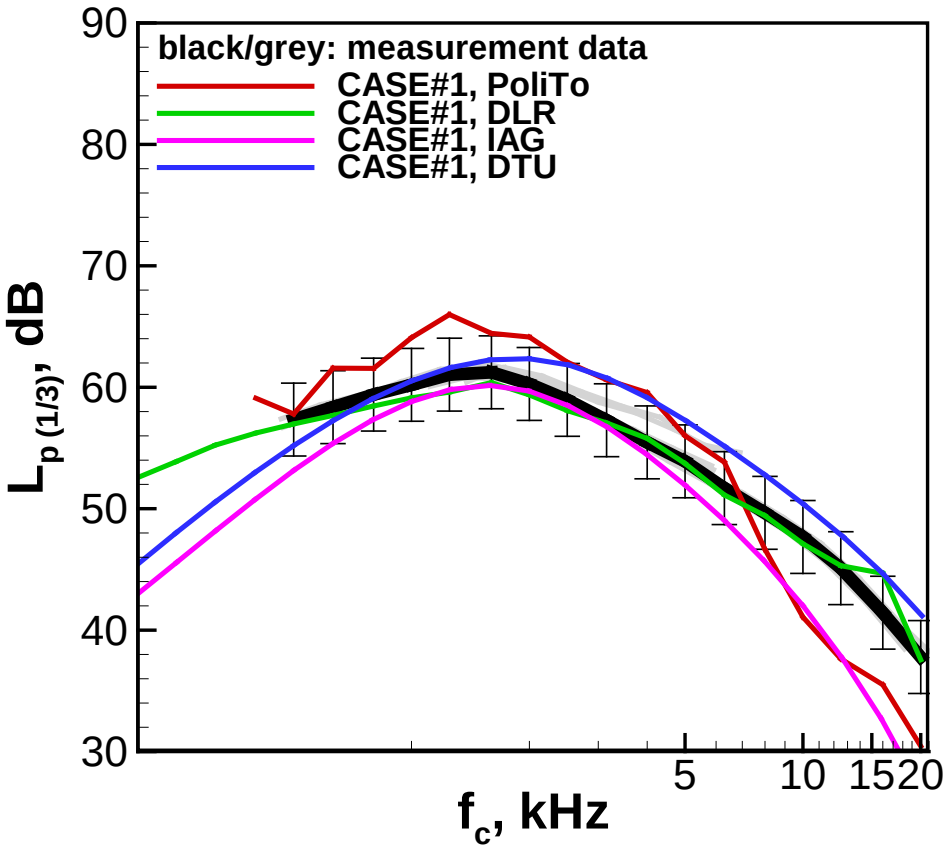
θ = 90° chord-normal
view direction for noise prediction

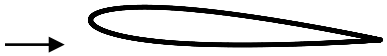
DLR

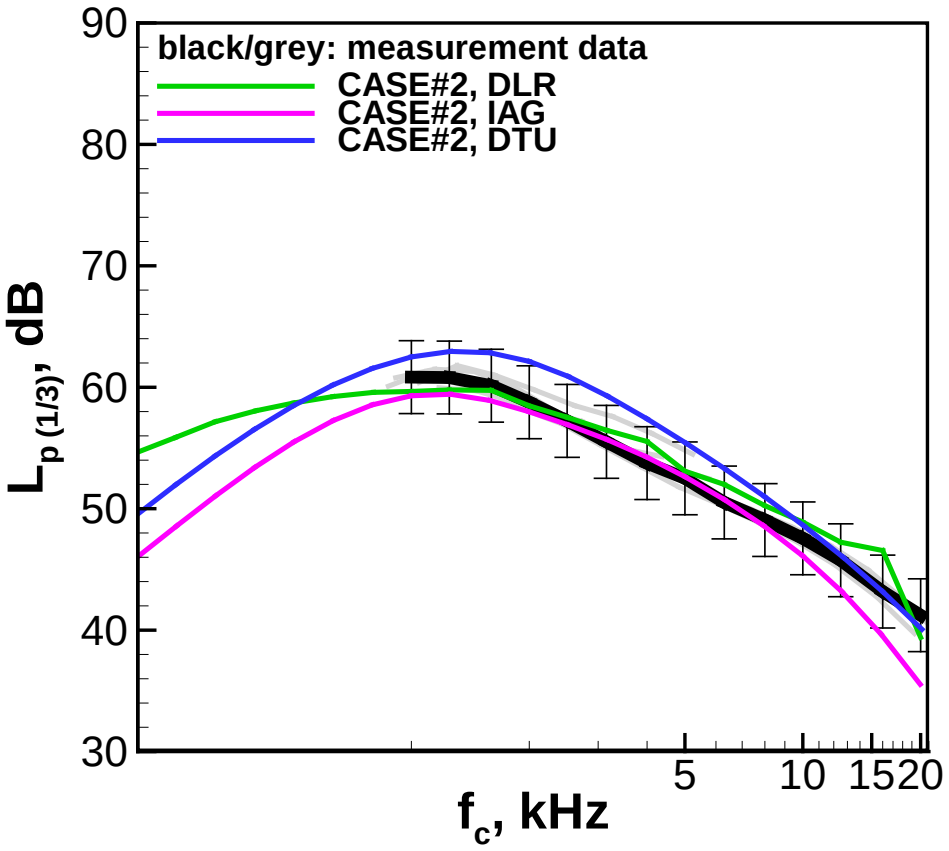


1/3-octave band FF noise spectra $L_{p(1/3)}(f_c)$ CASES#1 & #2

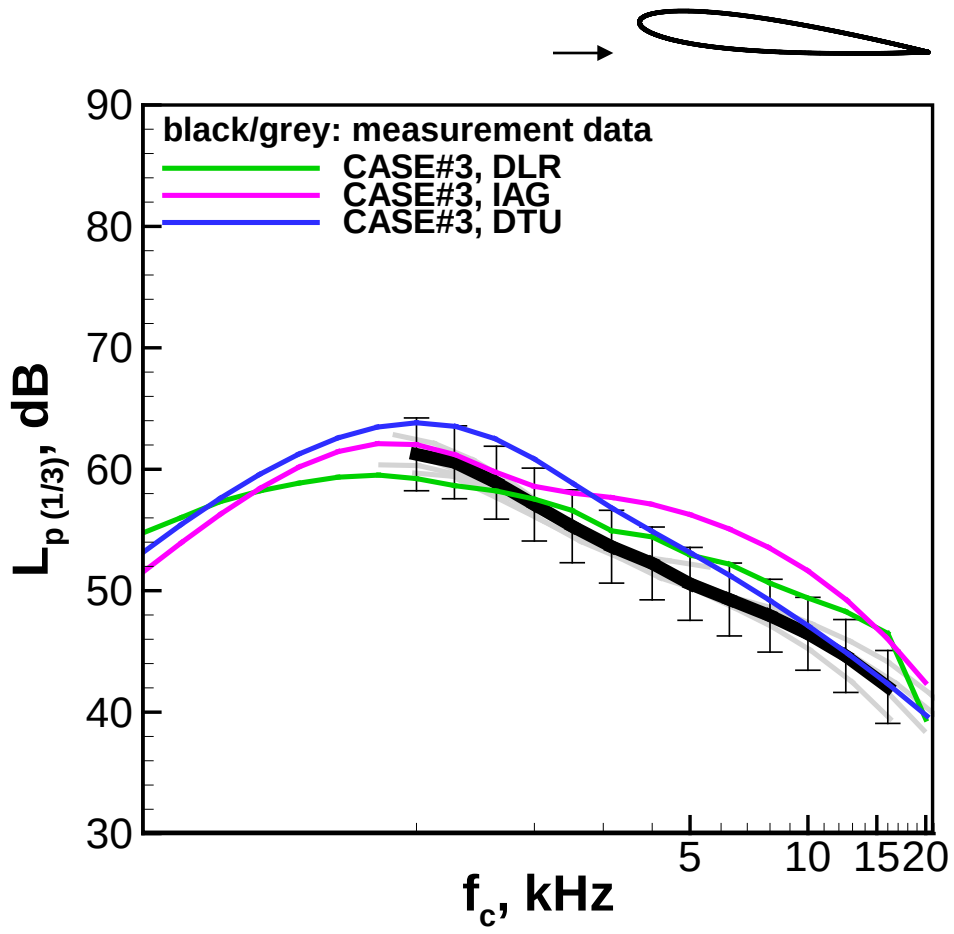


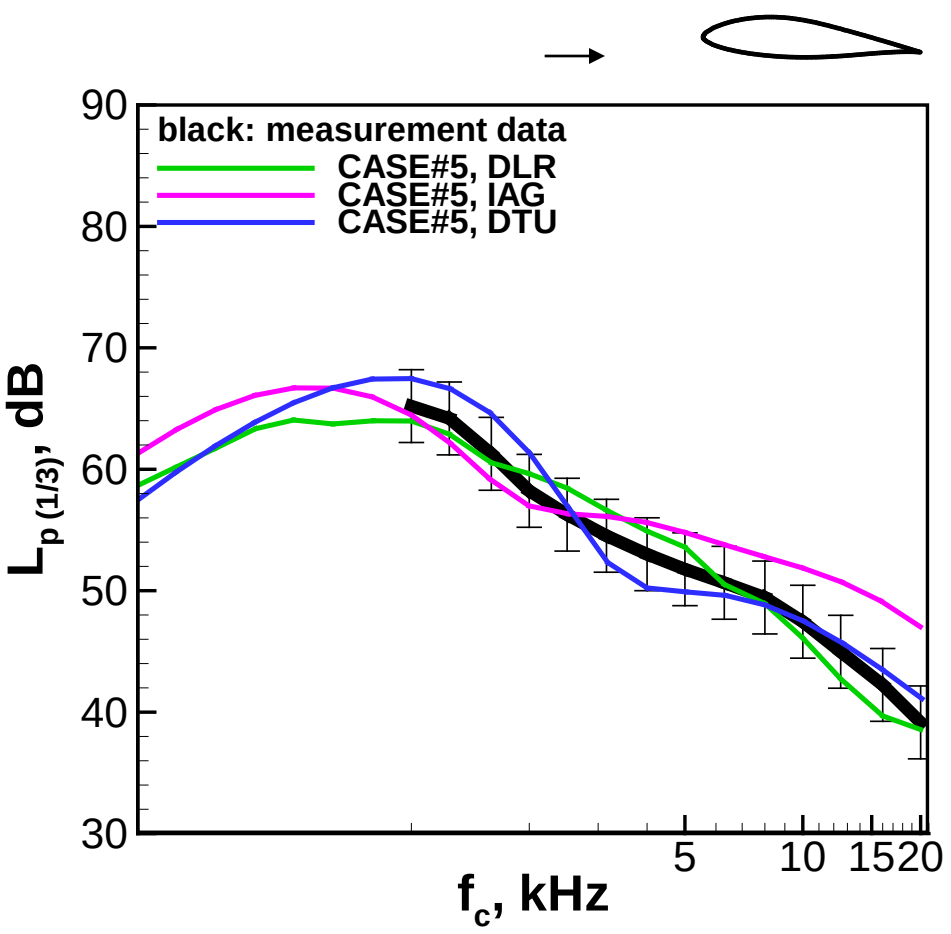






1/3-octave band FF noise spectra $L_{p(1/3)}(f_c)$ CASES#3 & #5





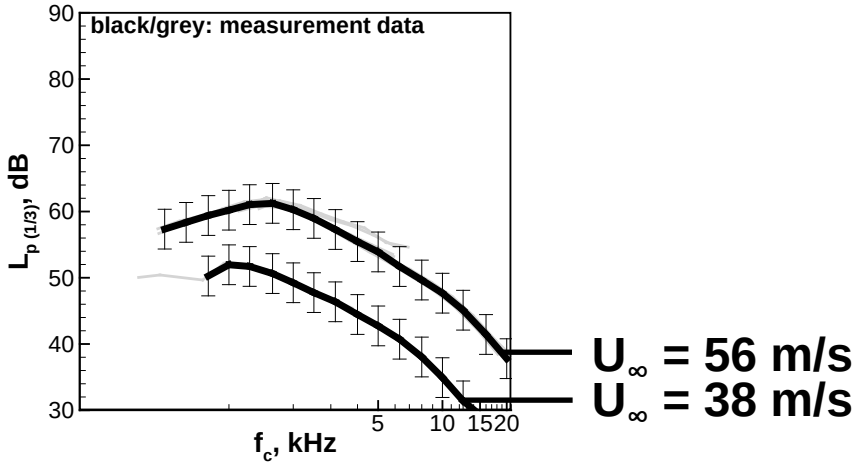
Overall comparisons

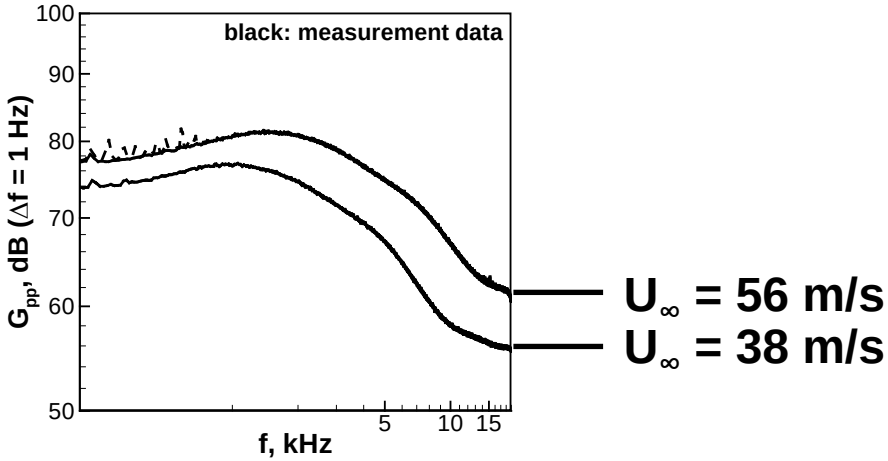
Pressure data

Pressure data revisited to identify common trends;

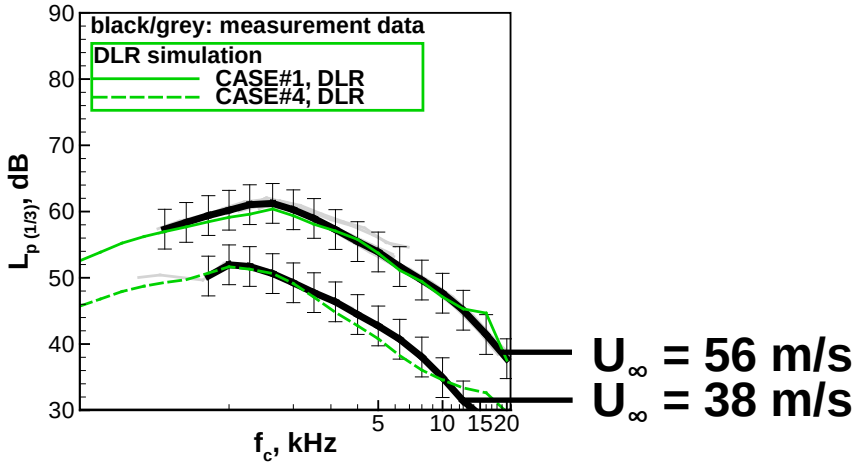
are relative effects captured by the predictions?

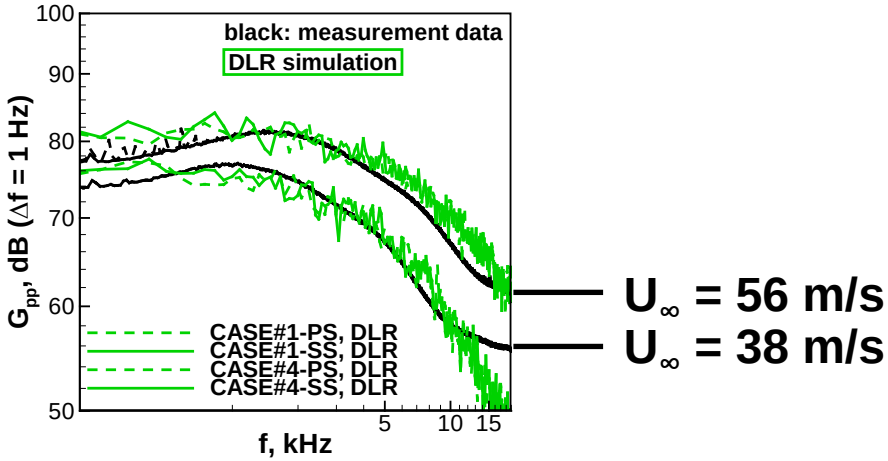
Effect of flow velocity on $L_{p(1/3)}(f_c)$ and $G_{pp}(f)$: CASE#1 vs. #4



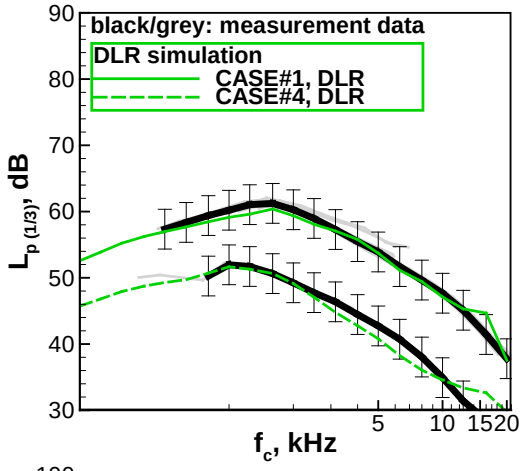


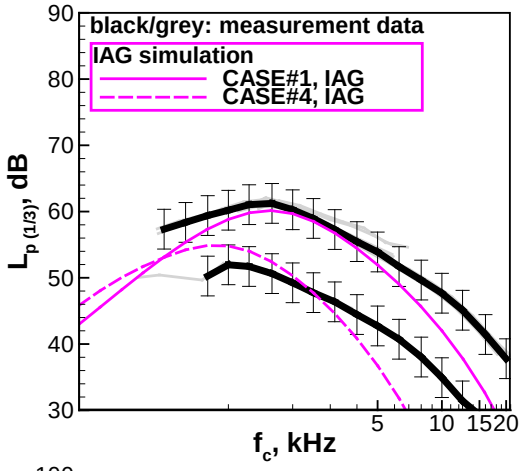
Effect of flow velocity on $L_{p(1/3)}(f_c)$ and $G_{pp}(f)$: CASE#1 vs. #4

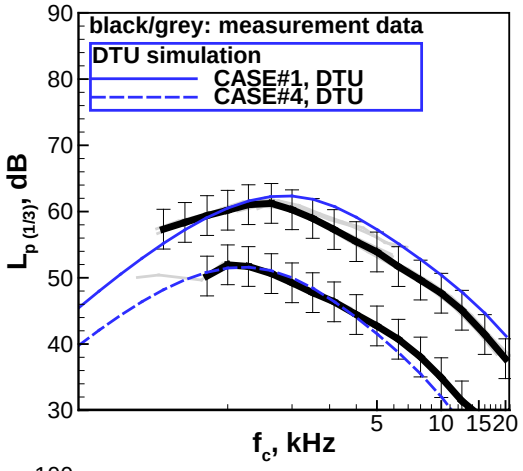


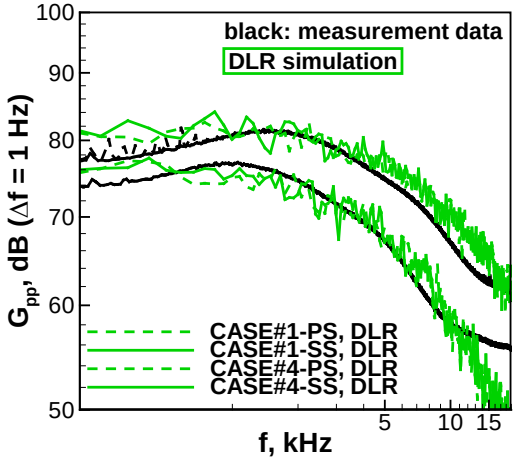


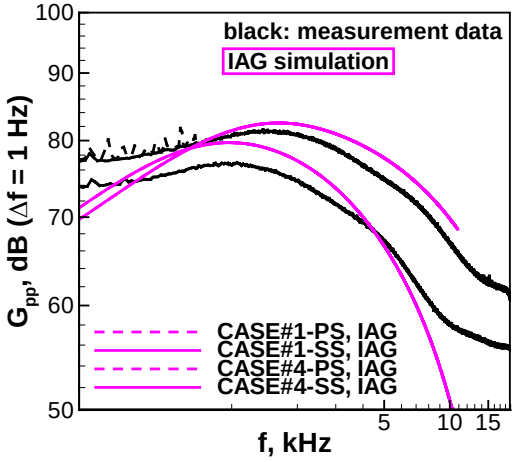
Effect of flow velocity on $L_{p(1/3)}(f_c)$ and $G_{pp}(f)$: CASE#1 vs. #4

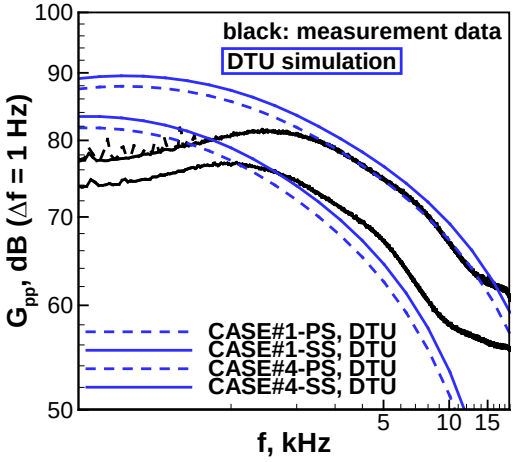




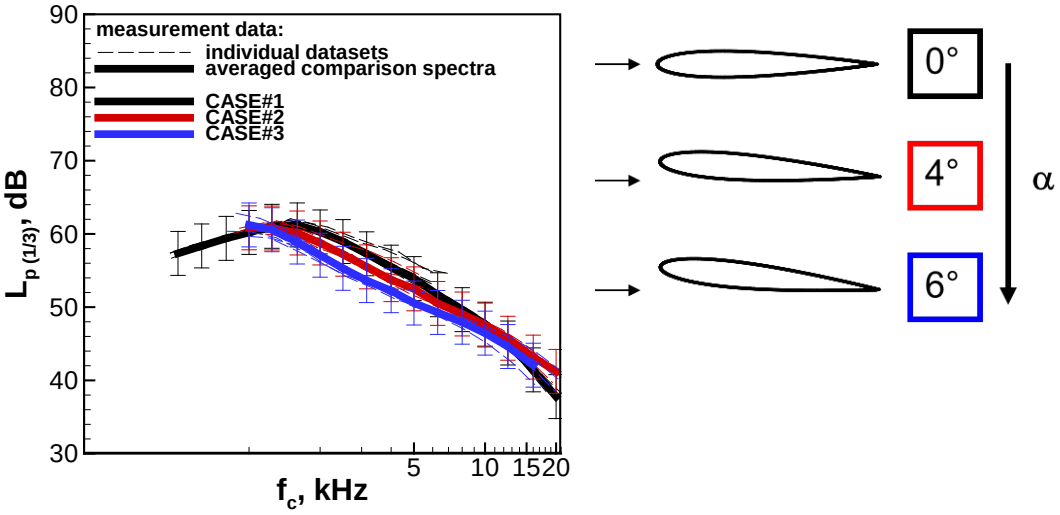


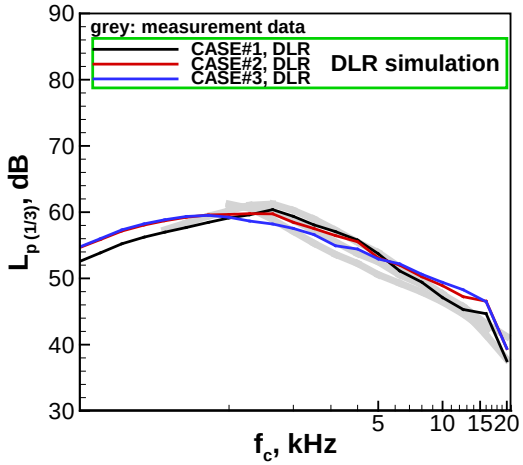


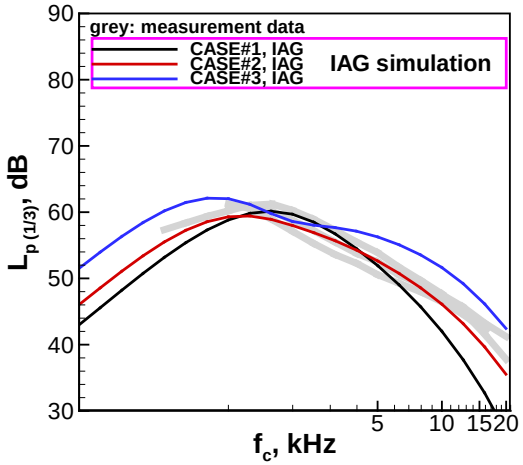


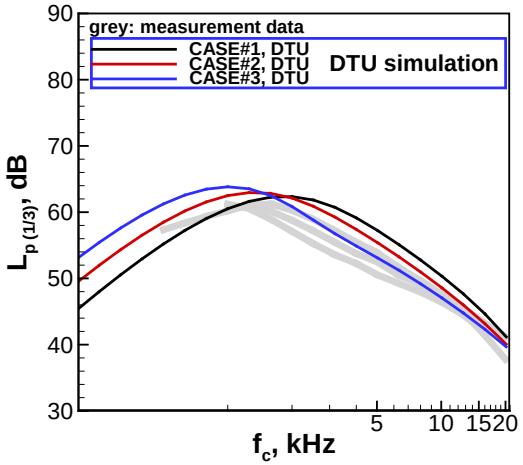


Effect of a-o-a on $L_{p(1/3)}(f_c)$: CASES#1 to #3



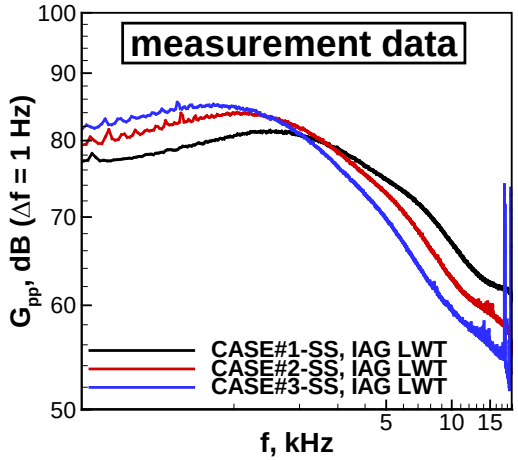


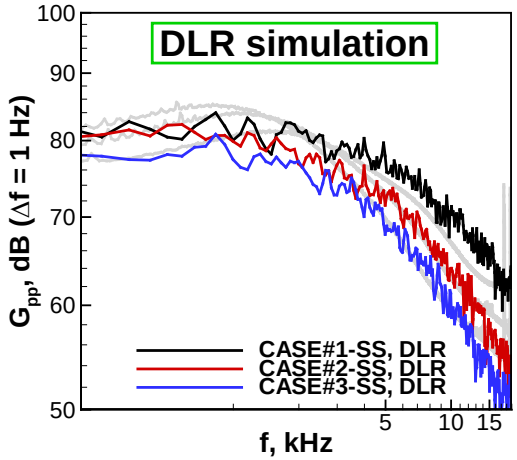


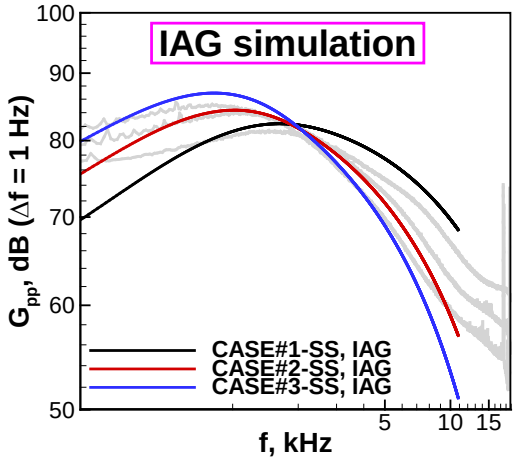


Effect of a-o-a on $G_{pp}(f)$: CASES#1 to #3

SS







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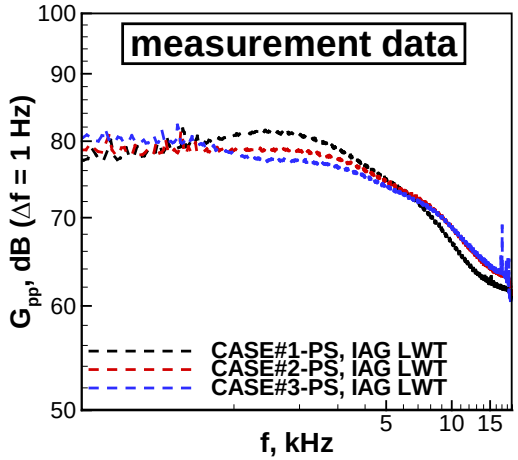
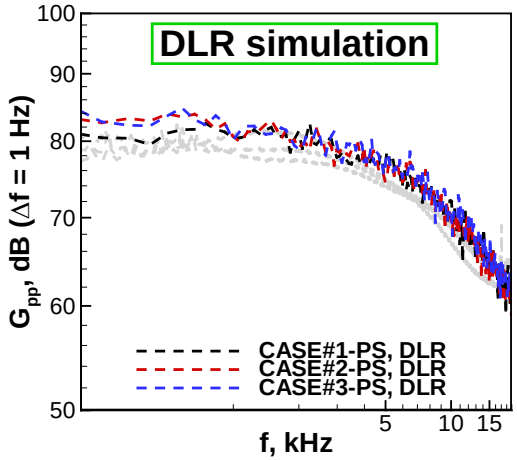
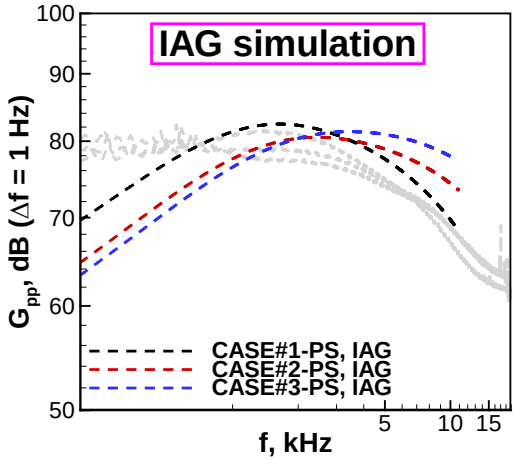
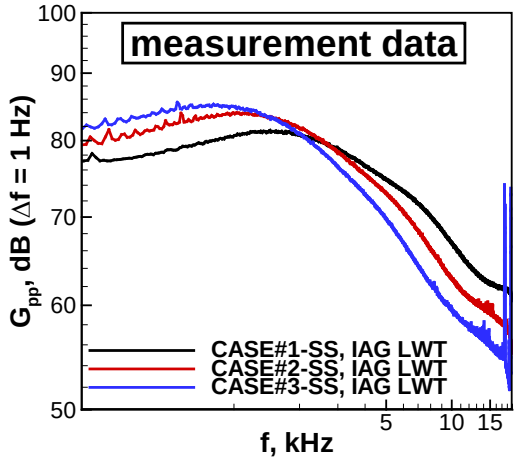


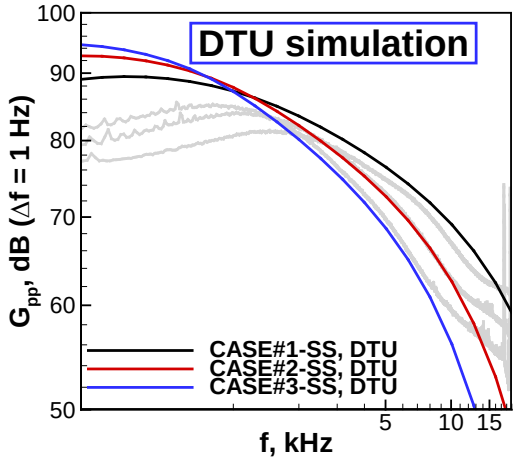


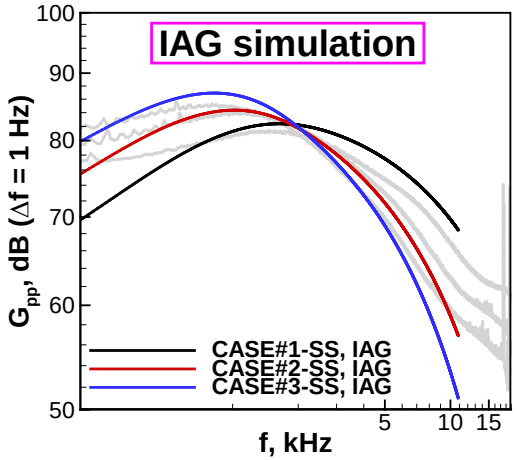


Effect of a-o-a on $G_{pp}(f)$: CASES#1 to #3

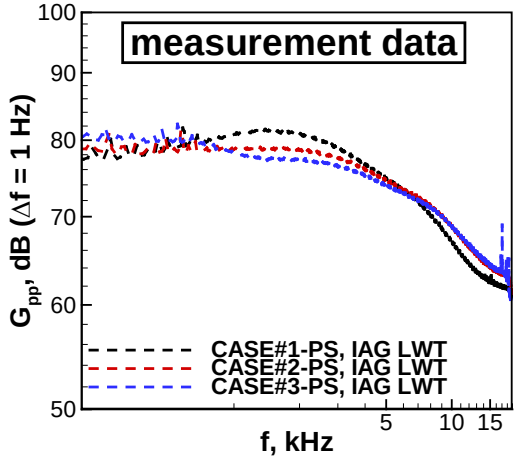
SS

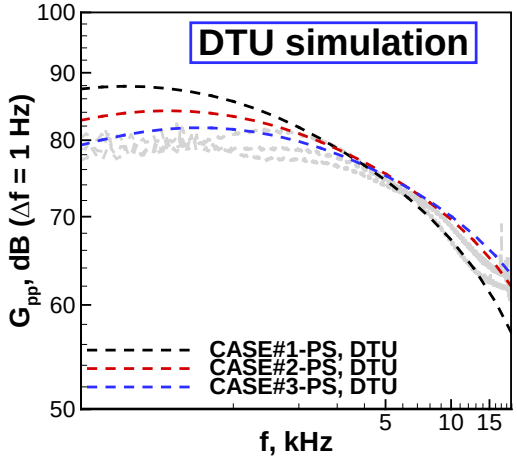


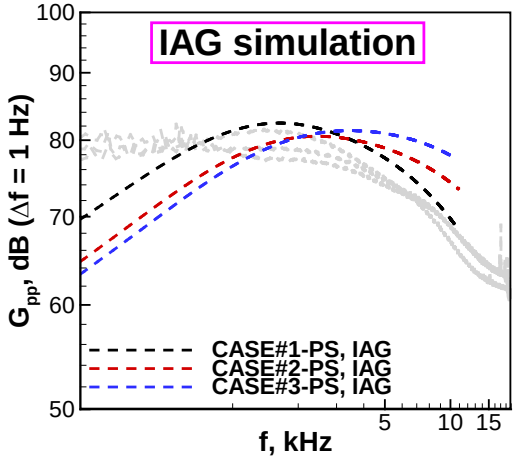




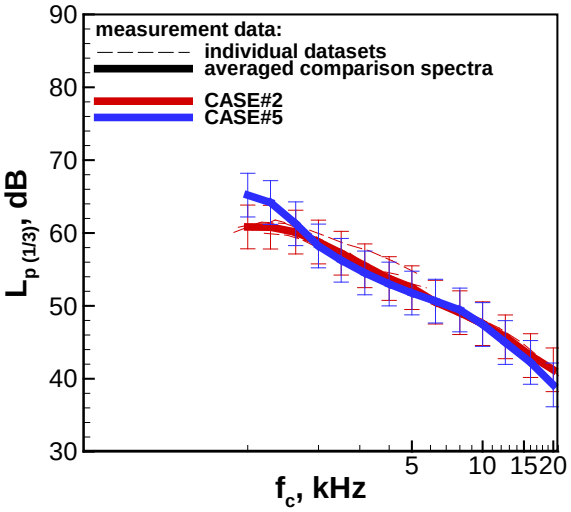
PS

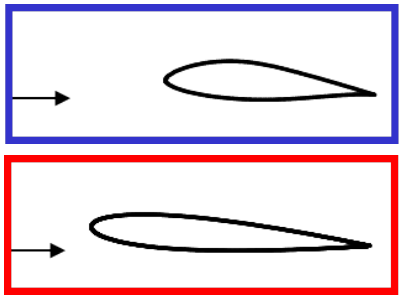


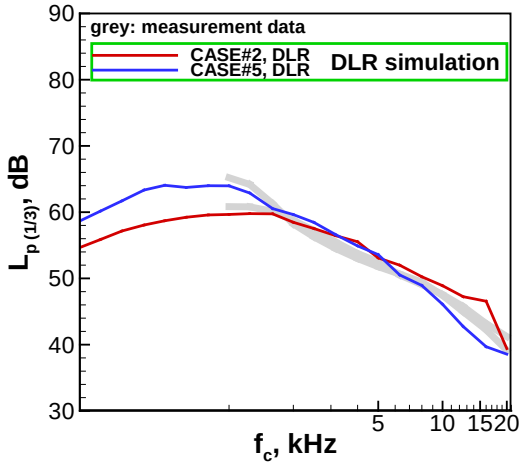


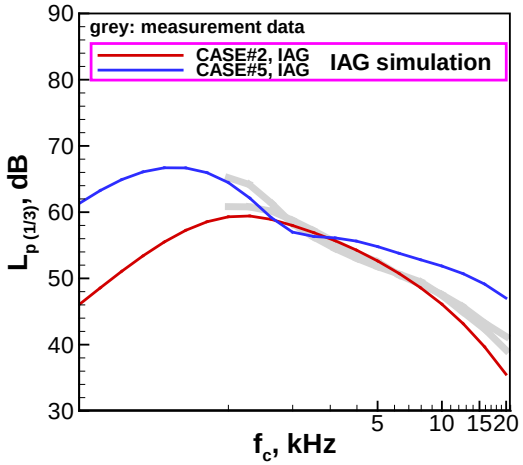


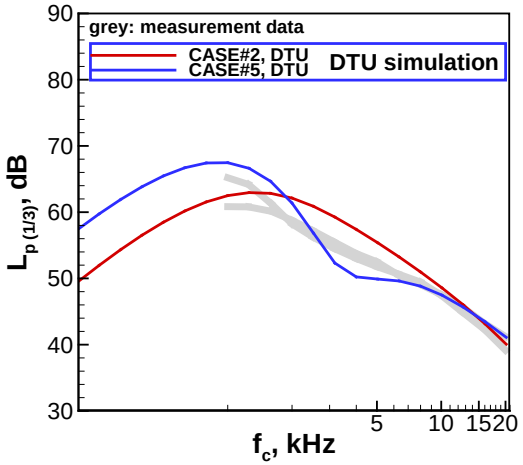
Effect of airfoil geometry on $L_{p(1/3)}(f_c)$: CASE#2 vs. CASE#5



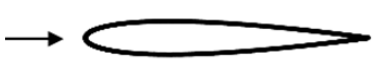




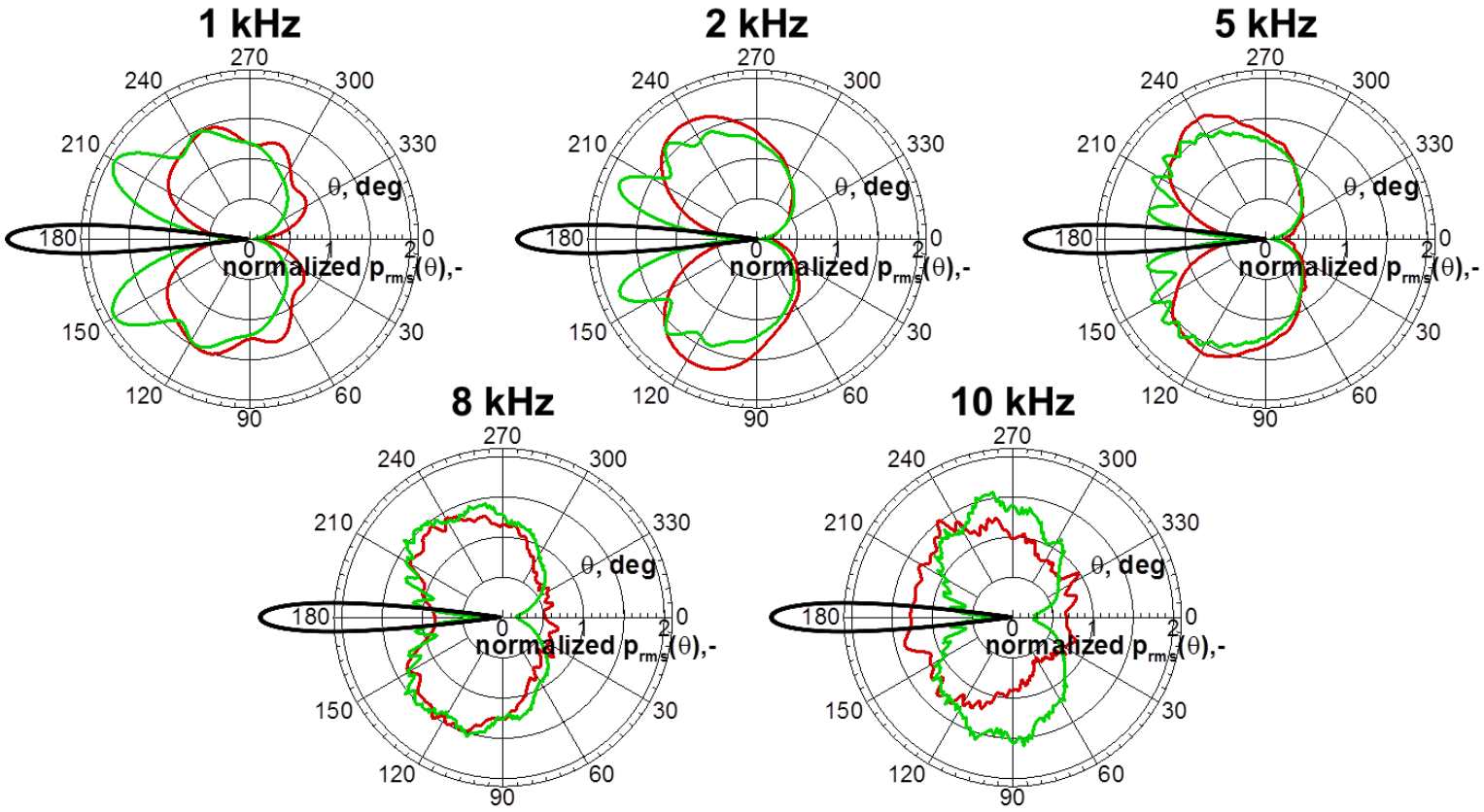




TEN directivities CASE#1

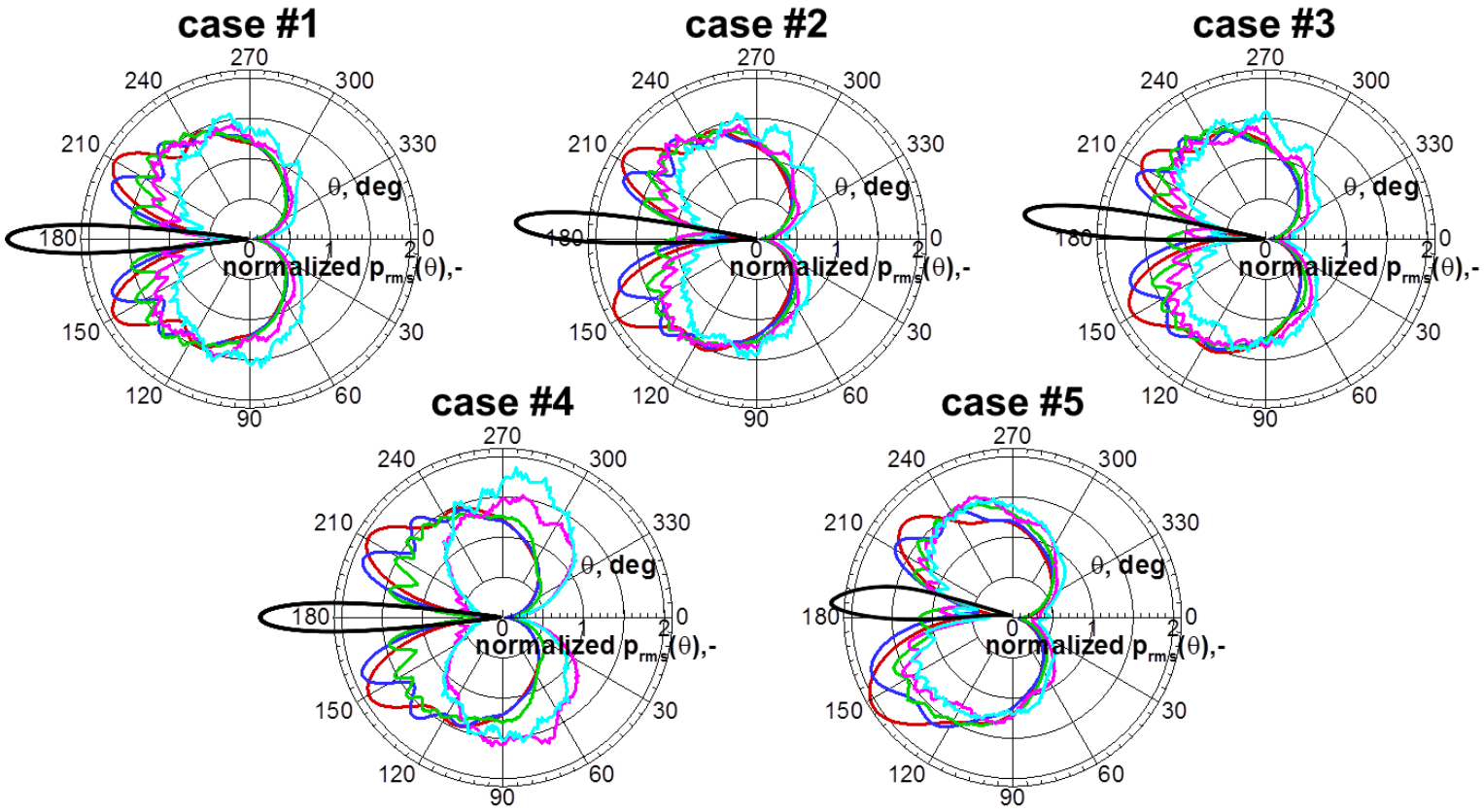


PoliTo DLR



TEN directivities CASES#1 to #5

1 kHz 2 kHz 5 kHz 8 kHz 10 kHz



Conclusions

- The outcome of the BANC-III workshop category 1 has been summarized.
- Results display a high scientific quality level; FF TEN predictions are within or very close to the provided data scatter band, TEN maxima are principally well-predicted; but:
  - General trends (a-o-a, velocity scaling) are not always correctly predicted.
  - Code-specific advantages/disadvantages are observable, indicating that a methodology which comprehensively predicts all of the requested nearfield & FF quantities is not available to date.
- The category 1 workshop problem remains a challenging simulation task due to its high requirements on resolving/modeling of TBL source quantities.
- We still faced a comparatively low number of participants, these were mainly developers of faster approaches dedicated for use in an industrial context (design-to-noise), BANC-III-1 results will hopefully activate multiplied follow-on activity by anyone interested to join the community.

Outlook

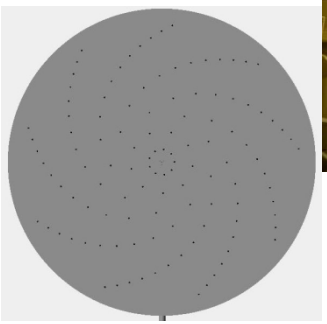
- We hope to motivate a more representative spectrum of the TEN community to participate at BANC-IV-1 in 2016.

- BANC-IV-1 will supplement the existing CASES#1–5 by additional datasets:
  - **0.6-m chord NACA64-618** data provided by DTU Wind Energy; $c_p(x_1)$, flow profiles, $L_{p(1/3)}(f_c)$, $G_{pp}(f)$, spanwise correlation of G_{pp}; **Re = 1.43 Mio.**

Case#6	**45.03 m/s -0.88°**	
Case#7	**44.98 m/s 4.62°**	

A. Fischer, 2011

array @ VTST



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- The by now established BANC category 1 data base is open for use to anyone interested and will be maintained according to your feedback.

- The BANC-IV-1 updated problem statement will be soon available; if you wish to be included in the distribution list please contact:

michaela.herr@dlr.de

Thank you for your attention!